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A Guide to Accompany

EMF_SCHOOL: A Decision Tool for Magnetic Field Standards in California Schools

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Abstract: The California Department of Health Services has been charged with recommending policies for managing possible health risks posed by power-frequency magnetic fields in California public schools. Magnetic field standards for schools are one policy option under consideration. Whether to adopt such standards, and if so, at what level and to address what sources, are matters of active discussion. To illuminate this discussion, we have developed a computer tool to estimate the exposure reduction, health risk savings, costs, and cost-effectiveness associated with various magnetic field standards. The tool is designed to make it easy for stakeholders and policymakers to explore the sensitivity of costs and benefits to changes in a variety of key factors, including beliefs about EMF health impacts, mitigation costs, willingness to pay for health enhancing interventions, and the rate of discount for future health savings. This document describes the assumptions and quantitative relationships underlying the tool, and provides guidance on how to operate the program.

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1. Introduction

This guide describes the structure and function of a computer model, dubbed EMF_SCHOOL, to compare the costs and health risk benefits of alternative standards limiting exposures to 60 Hz magnetic fields (EMFs)[1] in California schools. The purpose of EMF_SCHOOL is to facilitate understanding and discussion among policy makers and stakeholders as they contemplate alternatives for managing EMF exposures in California schools. The model addresses policies that are applied to the state as a whole, and cannot be used to address EMF problems in any particular school.

Much of the magnetic field exposure and cost data for EMF_SCHOOL are derived from a study of magnetic fields in 89 California schools conducted by Enertech Consultants. Users of EMF_SCHOOL may find it helpful to read Enertech's final report (Zaffanella and Hooper 2000), hereinafter referred to as "Zaffanella and Hooper 2000."

Any model is an abstraction of reality. Our goal in modeling the costs and benefits of exposure standards in schools is to create the simplest abstraction capable of providing insight into the most important features of the problem. These insights include (i) appreciation of the sensitivity of outcome variables (e.g., net benefits) to a variety of assumptions about exposure, health effects, and economics, (ii) understanding trade-offs between mitigation costs and various benefits of exposure reduction, and (iii) developing a sense of what variables contribute most to decision uncertainty.

There are large uncertainties in the health risks of EMFs, smaller but significant uncertainties in EMF exposures from various sources, and perhaps an order of magnitude uncertainty in unit mitigation costs. Given these large uncertainties in a number of key model variables, improvements in the accuracy or completeness of other parts of the model do not help inform the choice of policy alternative, but can add complications to the model that make it harder to understand. We have made a number of simplifying assumptions consistent with preserving the gross behavior of the system. For instance, we consider only exposure in classrooms, because that is where children and staff spend most of their time. Including other areas would approximately double the costs of meeting a field strength standard (Table 1.1) but would not significantly increase exposure reductions.

Table 1.1. Cost estimates [from Enertech CAL software,(Zaffanella and Hooper 1998)] for meeting average areas standards in all school areas versus classrooms alone (including option of limiting access to classrooms).

Exposure Standard (average for area)	Applied to all areas	Applied to classrooms only
1 mG	$224 million	$109 million
2 mG	$81 million	$40 million
5 mG	$20 million	$13 million

In their survey of magnetic field levels in schools, Zaffanella and Hooper (2000) identified ten classes of magnetic field source. For simplicity, EMF_SCHOOL models exposure from four of these that, together, account for 86% of the spatially-averaged classroom magnetic field level above 0.5 milligauss. These sources are net currents, electrical panels, distribution lines, and transmission lines. Including other sources would slightly increase estimates of both the benefits and costs of exposure reduction (see Figs. 12.5 and 12.6 in Zaffanella and Hooper 2000).

[1] Although EMF is sometimes taken to mean "electric AND magnetic field," and other times "electromagnetic field," it is used here to mean "magnetic fields at power-frequency."

EMF_SCHOOL includes both quantitative (e.g., background levels of EMF exposure in classrooms) and qualitative (e.g., the probability that EMF health effects are real, willingness-to-pay for investments in life-saving interventions) factors in the interest of being inclusive of the factors that figure strongly in peoples' calculus. Key variables are represented using a range of values from which the user can choose, according to their own judgment. In addition to facilitating discussion on costs and benefits of possible standards, EMF_SCHOOL allows users to do a variety of sensitivity analyses to explore which factors are most critical to the endpoints of interest.

EMF_SCHOOL considers only existing schools, not new schools. The focus on existing schools is based on the much larger population that would be immediately affected by policies concerning existing schools, as well as the fact that the costs of reducing EMF exposures in new schools is much lower than the costs of reducing exposures in existing schools.

EMF_SCHOOL is implemented in Analytica,[2] a graphically-oriented programming language designed especially for doing policy analysis. Models in Analytica are represented graphically as influence diagrams. Users can investigate model details simply by clicking on nodes of the influence diagram that represent variables of interest. Analytica incorporates uncertainty by representing input and output variables as probability distributions. This makes it possible to tell whether differences in the net benefits of two policy alternatives are significant in light of the uncertainty in the estimates of those outcomes. Analytica is designed so that models can be internally documented. Variables are displayed with both a mathematical definition and a verbal description. Much of the information contained in this document can also be found in the model itself, attached to the nodes representing each variable.

2. Policy Options Modeled

EMF_SCHOOL estimates the costs of benefits of 60-Hz magnetic field standards applied to California public school classrooms. Classrooms alone are considered because that is where students and teachers spend most of their time. The model computes costs, benefits, and cost-effectiveness for each source separately and for all sources together, to allow for consideration of standards applied only to particular sources. The model computes results for all schools, and for elementary and middle/high schools separately, to allow for consideration of standards applied only to particular student age-groups.

Currently, EMF_SCHOOL computes results for standards of 5 mG, 2 mG, 1 mG, and 0.5 mG. We consider only standards up to 5 milligauss, because there are so few exposure situations above that level that statewide costs and benefits are small. We do not model the ICNIRP [3] field limit (833 milliGauss) because it is indistinguishable in cost and benefit from no limit (the status quo). We do not explicitly list a "no standard" option because no standard is the status quo. By definition, the model computes changes in costs and benefits from the status quo.

Standards can be based on either average or worst-case fields in classrooms. Results for standards applied to powerline exposures are computed using spatial-average fields in classrooms because powerline fields are relatively uniform across a classroom dimension. For standards applied to net currents or electrical panels, however, the user can choose to apply a standard based on either the spatial-average classroom field or the 95th percentile field (i.e., the source field exceeded in only 5% of the classroom space). In a classroom with 20 children, 5% of the area would represent the desk area of one child.

[2] Analytica is available from Lumina Decision Systems, Los Gatos, California. A demonstration version of Analytica can be downloaded for free from their website at www.lumina.com.
[3] The ICNIRP (Intl. Commission on Non-ionizing Radiation Protection) guidelines appear in *Health Physics*, Vol. 74, (4):494-522 (April '98).

3. Uncertainty, Variability, Values, and Judgment

EMF policy models contain many kinds of uncertainty. Some parameters are well-known, but vary across the population (e.g., average classroom exposures in elementary versus high schools). Some parameters are uncertain because measurements are sparse (e.g., number of students in California chronically exposed to fields > 5 milligauss). Other parameters are uncertain because the science is muddy (e.g., dose-response coefficient for childhood leukemia). Finally, some parameters are uncertain because they are matters of value (e.g., willingness to pay for life-saving interventions) or of judgment (e.g., probability that EMF health effects are real). In EMF_SCHOOL, these various kinds of uncertainty are treated either by assigning probability distributions to variables or by representing variables by a set of discrete values from which the user can choose. To reduce computational complexity, point estimates (best estimates) are used whenever uncertainties are relatively small (e.g., number of students in California schools).

4. Model Structure, Inputs and Outputs

The top-level structure of EMF_SCHOOL is shown in Figure 4.1. The model contains several modules that (1) define school characteristics, (2) establish background exposure levels and exposure reductions resulting from standards, (3) estimate background health status and estimate health improvements resulting from standards, (4) value those health improvements in monetary terms, (5) estimate mitigation costs, and (6) compute various measures of policy performance such as net benefits, cost-effectiveness, and life-years saved.

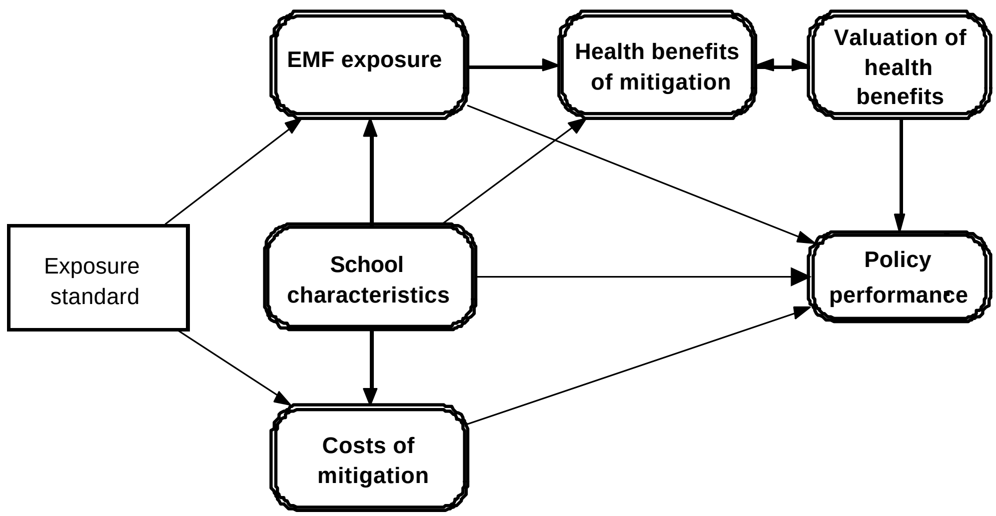

Figure 4.1. Top-level structure of EMF_SCHOOL model.

This guide describes the general features of each of the model's various modules and submodules. For details on the definitions and relationships between variables, users should refer to the internal documentation in the model itself.

4.1 School Characteristics Module

This is the simplest of the six modules. It contains general information on California schools (see Table 4.1), including numbers of schools of different types, number of classrooms, and the number and sex ratio of students and staff by age group. These variables are used by a number of other modules. Data for the parameters in this module are taken from the Enertech 89 school survey, from "School Facilities Fingertip Facts", by the School Facilities Planning Division, California Dept. of Education, December, 1997, and from the California Department of Education's website.

As EMF_SCHOOL only computes the costs and benefits of exposure reduction for classrooms, it does not include estimates for office and maintenance staff who might also work indoors. We have found no data on the number of non-teaching staff in California schools, but we believe it to be small compared to the numbers of teachers and other certificated staff who spend time in classrooms. Further, the number of non-classroom staff-occupied rooms (e.g., offices, kitchen) in the Enertech 89-school dataset is small compared to the number of classrooms. For these reasons, we believe that the total costs of addressing fields in all staff-occupied indoor spaces will not be greatly different from the costs computed by EMF_SCHOOL for addressing only classrooms. As the types of sources in non-classroom indoor spaces do not differ from the types of sources in classrooms, and because the number of persons (students and staff) in classrooms is significantly greater than in other indoor areas, we would expect the cost-effectiveness ($ per person-mG) of field reductions for non-classroom indoor spaces to be worse than for classrooms. Therefore, including rooms occupied by non-teaching staff in the calculations for the total school would worsen the overall cost-effectiveness of a given exposure standard.

Table 4.1. Statewide school-related statistics used in EMF_SCHOOL model. Values shown as ranges are entered in model as uniform distributions across the specified range.

Statistic	Value	Reference
Total classrooms	268,300	Zaffanella and Hooper 2000
Total K-12 students	5,950,000	www.ed-data.k12.ca.us/state/statewideprofile97.asp
Total elementary schools (K-6)	5,311	www.ed-data.k12.ca.us/state/statewideprofile97.asp
Total middle & high schools (7-12)	2,062	www.ed-data.k12.ca.us/state/statewideprofile97.asp
Total teaching staff	265,000	Calif. Dept. of Education website
Fraction of staff who are female	71%	Calif. Dept. of Education website
Fraction of elementary schools with pre-K classrooms	11%	Enertech 89-school database
Children per pre-school classroom	10-25	Estimate
Pupil-teacher ratio, grades K-6	20.4	www.ed-data.k12.ca.us/state/statewideprofile97.asp
Pupil-teacher ratio, grades 7-12	23.7	www.ed-data.k12.ca.us/state/statewideprofile97.asp
Teachers per pre-school classroom	1.5-3.0	Estimate
Teachers per K-6 classroom	1	www.ed-data.k12.ca.us/state/statewideprofile97.asp
Teachers per 7-12 classroom	1	www.ed-data.k12.ca.us/state/statewideprofile97.asp

4.2 Exposure Module

This module estimates the population exposure reductions associated with a given EMF exposure standard for each of four classes of EMF sources: net currents, electrical panels, distribution lines, and transmission lines. There are separate exposure submodules for each of these four source types. The exposure submodule for each source includes parts that compute background exposures for that source and exposure reductions for that source, under various proposed exposure standards. In general, exposure calculations are indexed by age group and school type as well as by source.

Many variables in the exposure module are drawn from data generated by Enertech's survey of EMF levels and sources in 89 California schools. Although the Enertech effort vastly increased available information about exposures in schools, the number of schools Enertech examined is still too small to permit accurate estimates of the number of situations in the entire state in which students or staff are exposed to fields greater than several milligauss. For this reason, we have fit probability distributions to the Enertech data at lower field strengths to estimate the number of cases at higher field strength. For instance, the Enertech data contain no cases in which classroom average fields from distribution lines exceed 5 mG. This does not mean, however, that there are no such cases in the entire state. To estimate how many cases lie above 5 mG in the 7000+ schools in the entire state, we fit a probability distribution to the Enertech data. Estimates of the number of extreme exposure situations in state are derived from this probability distribution. At the upper end, probability distributions are truncated when values are not physically realizable. For instance, classroom fields from transmission lines are assumed to never exceed 20 mG. Details on how exposure distributions were derived from the Enertech data can be found in the exposure submodules for each source type. An appendix to this document shows probability distributions that were fit to the Enertech results and incorporated into this policy model.

For reasons of practicality, Enertech did not try to identify magnetic field sources that create less than 0.5 mG in area. Exposure reduction computed by EMF_SCHOOL, therefore, do not include any reductions that might occur among classrooms with pre-mitigation fields of 0.5 mG or less. These exposure reductions would be expected to be quite small, however, compared to those from reducing fields in classrooms with higher field strengths. While it is true that classrooms with fields below 0.5 mG contribute a substantial portion (about 30%) of overall pre-mitigation exposure, low-field classrooms contribute a much smaller portion to the exposure reductions achieved by exposure standards.

Magnetic fields from different EMF sources add vectorially, so eliminating one source in a classroom with multiple sources does not reduce the classroom field strength by an amount equivalent to the field strength produced by that one source alone. EMF_SCHOOL makes the simplifying assumption that the magnetic fields from different sources do not overlap, so full credit is taken for reducing fields from each source. In the Enertech dataset, fully 82% of classrooms with at least one area source have <u>only</u> one area source. EMF_SCHOOL estimates exposure reduction correctly for these 82%, but overestimates the exposure reduction for the remaining 18%. For this 18%, an estimated exposure reduction of one unit is, in actuality, only an exposure reduction of about 0.4 units.[4] The combined effect of reductions in both single source and multi-source classrooms is to overestimate the total exposure reduction for all classrooms by about 27%. Given the much larger sources of uncertainty in other components of this model, we view a bias of this magnitude as worth the benefits of model simplification that the assumption on source independence provides.

Similarly, in calculating exposure reductions, EMF_SCHOOL does not account for low-level fields created by unidentified sources, which, according the Enertech 89-school dataset, are responsible for background levels of approximately 0.2 mG in classrooms. Ignoring these background fields will result in overestimating exposure reductions by an average of about 0.1 mG per case.

4.2.1 Net Current Exposure Submodule

Pre-mitigation population exposure to magnetic fields from net currents are estimated by taking the sum over school types and age groups of the sum of population exposure from net currents in a series of contiguous field strength bins:

[4] For instance, consider two sources, each of strength X, and producing a combined strength of $(X^2+X^2)^{1/2}$. Eliminating just one of them will reduce the field from 1.4X to X, a net reduction of 0.4X. But EMF_SCHOOL would credit a reduction of X for eliminating one source.

$$X_{nc-premit} = \sum_s C_s \left[\sum_a P_{sa} \;\; f_{nc} \left(\sum_i f_i B_i \right) \right] \qquad \textit{Eqn. 4.1}$$

where

$X_{nc-premit}$ = time-weighted average population exposure from net current in person-milligauss,

C_s = number of classrooms statewide of school type *s* (i.e., elementary, middle/high).

P_{sa} = number of persons per classroom of school type *s* and age group *a*,

f_{nc} = fraction of classrooms that are "net current classrooms," defined as having net current fields exceeding 0.5 mG in at least 5% of the classroom area

i = index for field strength bin, running in 0.5 mG increments from .5 mG to 20 mG

f_i = fraction of net current classrooms with spatially-averaged net current fields in bin *i* (e.g., between 1.5 and 2.0 mG),

B_i = average magnetic field level for field bin *i* (e.g., 1.75 mG for the 1.5-2.0 mG bin).

Values for the variables in Equation 4.1 are obtained as follows.

C_s and P_{sa} are taken from Table 4.1 above.

The fraction of classrooms that are affected by net current fields, f_{nc}, is estimated from the Enertech 89 school database to be roughly 0.36.

The Enertech 89-school database show (Figure 9.1) that the fraction of net current classrooms with spatially-averaged net current fields greater than B is

0.68	for B =0.5 mG and
$0.282/B^{1.6}$	for 1.0 mG < B < 20 mG.

The fraction of net current classrooms with 95% net current fields less than B is

1.0	for B=0.5 mG and
$1-0.614/B^{1.3}$	for 1.0 mG < B < 20 mG.

The fraction of net current classrooms with net current fields of various strengths, f_i, is derived from the above expressions for the cumulative distribution by subtraction of the cumulatives in adjacent field strength bins.

We assume that there are no cases in the state where 50th and 95th percentile net current fields can exceed 20 mG. Actually, in the Enertech dataset, a very small fraction (0.5%) of the net current classrooms have 95th percentile fields exceeding 20 mG (maximum of 32 mG in a sample of 820 classrooms). We have limited our analysis to 20 mG in EMF_SCHOOL to conserve memory storage and allow faster model runtimes. This will result in a slight underestimate of exposure reductions from fixing net currents.

Exposure reduction for net currents is estimated as follows. The number of classrooms affected by net currents producing field levels that exceed the field standard can be found from f_i above. Net current exposures in these classrooms are assumed to be eliminated by the field standard. Since each net current typically influences more than one classroom, however, it is necessary to account for reductions in net current fields that occur in classrooms that have field levels below the standard as well. According to the Enertech data, each net current source affects an average of 1.6 classrooms. Let

f_s = fraction of net current classrooms above the standard
NCC = total number of net current classrooms
NCperClsrm = average number of classrooms affected by each net current source (i.e., 1.6)

Then the total number of net current sources that would need to be fixed with a given field strength standard is approximately

$$NC_{fixed} = \frac{f_s\ NCC}{1 + f_s\ (\text{NCperClsrm - 1})} \qquad \textit{Eqn. 4.2}$$

Because each net current source affects more than one classroom on average, the number of net current sources that need to be fixed under a standard is smaller than the number of net current classrooms above the standard, f_s**NCC*. We assume that the additional (NcperClsrm-1) classrooms that are affected by eliminating a given net current are uniformly distributed, so the probability that the addition classroom lies above the standard is simply f_s.

Let NC_{below} = number of net current classrooms below standard that would be corrected by implementing the standard. This is approximately

$$\text{NClsrm}_{\text{below}} = \text{NC}_{\text{fixed}} * (\text{NcperClsrm-1}) * (1\text{-f}_{\text{s}}) \qquad \textit{Eqn. 4.3}$$

The fraction of classrooms below the standard that would be corrected by the standard is:

$$f_{below} = NClsrm_{below} / (1\text{-}f_s)*NCC \qquad \textit{Eqn. 4.4}$$

Post-mitigation population exposure from net currents is given by:

$$X_{nc-postmit} = \sum_s C_s \left[\sum_a P_{sa}\ \ f_{nc}\ \ f_{below} \left(\sum_{i=1}^{Stnd} f_i B_i \right) \right] \qquad \textit{Eqn. 4.5}$$

where *Stnd* is the field strength bin containing the field strength standard limit.

4.2.2 Electrical Panel Exposure Submodule

The electrical panel submodule computes baseline population exposure from electrical panels and the population exposure reductions that result from application of a field-strength standard. The electrical panel submodule computes exposures and exposure reductions separately for main and other electrical panels.

Out of a total of 2985 classrooms, the Enertech 89-school dataset has 30 classrooms (1%) with fields from main distribution panels that exceed 0.5 mG in at least 5% of the area. The standard deviation of the fraction of classrooms with main distribution panel fields is about sqrt(30)/2985= 0.0018. So a 95% confidence interval on the fraction of classrooms with main distribution panel fields would be 0.010 +/- 2*.0018. There are 240 classrooms in the dataset affected by other types of distribution panels, or 240/2985=.08 of all classrooms. The 95% confidence interval for this parameter is .08 +/- 2*sqrt(240)/2985.

The fractions of electrical panel classrooms with average and 95th percentile fields exceeding a given value were derived from the Enertech 89-school database and fit to lognormal distributions as shown in Figure 9.2.

Values of key parameters of the electrical panel submodule are shown in Table 4.2.

Table 4.2. Key parameter values for electrical panel exposure submodule. Values are derived from the Enertech 89-school database. GSD=geometric standard deviation.

Parameter	Value (main panels)	Value (other panels)
Fraction of classrooms affected by electrical panels (i.e., electrical panel field > 0.5 mG in at least 5% of area)	Uniform distribution from .006-.014	Uniform distribution from .07-.09
Distribution of spatially-averaged electrical panel field in electrical-panel classrooms	Lognormal distribution, median= .62, GSD=2.4	Lognormal distribution, median =.29, GSD= 2.4
Distribution of 95th percentile electrical panel field in electrical-panel classrooms.	Lognormal distribution, median = 2.5, GSD=2.4	Lognormal distribution, median = 1.2, GSD=2.4

Post-mitigation exposure from electrical panels is estimated assuming that electrical panel shielding effectively eliminates any significant exposures. This assumption is made so that the same model structure can be used for electrical panels as is used for net currents. Enertech estimates actual field reduction factors for electrical panel shielding to be about 8 for shielding areas on the back of the panel and 4 for shielding areas in front of the panel. The majority of electrical panels that affect classrooms require shielding in the back, so the overestimate of exposure reduction resulting from the assumption that electrical panel shielding eliminates all exposure is small compared to the total amount of the exposure reduction.

4.2.3 Distribution Line Exposure Submodule

Exposures to distribution and transmission line fields are modeled using similar sets of parameters. We define a “distribution line classroom” as any classroom that has a distribution line field of at least 0.5 mG in 50% or more of the classroom area. Unlike fields from net currents and electrical panels in classrooms, which change greatly from one side of the classroom to another, fields from distribution lines in classrooms are much more uniform. Therefore, the 95% classroom field and 50% classroom fields from distribution lines aren’t much different. In the Enertech 89 school database, for instance, the 95th percentile classroom field from distribution lines is only 32% greater, on average, than the 50th percentile classroom field. Given this modest difference, EMF_SCHOOL computes exposure and exposure reduction from distribution lines using only the 50% source field.

Distribution lines can affect more than one classroom per school. We define the “Bmax classroom” for a particular school as the classroom with the highest field level from that line. “Non Bmax classrooms” are all other distribution line classrooms with distribution line fields that exceed 0.5 mG. Population exposures to distribution lines are computed in two parts: those occurring in Bmax classrooms, and those occurring in non-Bmax classrooms. The reason for making this distinction is that requirements for field strength reduction are determined by field levels in only Bmax classrooms, since those classrooms represent the highest field levels from a given distribution line. In contrast to net currents and electrical panels, which we assume have mitigation options that are “all or nothing,” EMF field reduction options for power lines span a range of possible field reductions.

Distribution line population exposure is estimated as follows. Using the Enertech 89 school dataset, we find that the frequency density[5] of distribution lines affecting classrooms (e.g., produce 50% > 0.5 mG in at least one classroom) as a function of classroom average field strength is approximately $1/X^{A\max}$, where X is field strength in milligauss and $A_{max} \sim 2.2$. This frequency density function is applied up to a maximum plausible distribution line classroom field[6] of $B_{max\_max} = 7$ mG (see Figure 9.3). Integrating this distribution, we find the fraction of distribution lines for which Bmax is in the i^{th} field strength bin, B_i, (each of which is .5 mG wide):

$$f\_bmax_i = \frac{(B_i + .5)^{1-A\max} - B_i^{1-A\max}}{B_{\max\_\max}^{1-A\max} - .5^{1-A\max}} \qquad \textit{Eqn. 4.6}$$

Let

f_schls_w_dl_clsrm = fraction of schools with at least one "distribution line classroom." From the Enertech 89 school data, this parameter is estimated to range from .11 to .27, with a most likely value of .19.
D_lines_per_dl_schl = average number of distribution lines per distribution line school, estimated to be 1.17 from the Enertech dataset.
Nschls = number of schools in California

Then, the number of distribution lines producing 50% sources fields > 0.5 mG in at least one classroom is:

$$Ndl = Nschls*f\_schls\_w\_dl\_cls*D\_lines\_per\_dl\_sch \qquad \textit{Eqn. 4.7}$$

And, the number of distribution lines producing Bmax fields in the i^{th} field strength bin is:

$$Ndlbin_i = f\_bmax_i * Nschls * f\_schls\_w\_dl\_clsrm \qquad \textit{Eqn. 4.8}$$

Let
$N\_dl\_cls\_in\_dl\_schl_i$ = mean number of distribution line classrooms per distribution line with Bmax in the i^{th} field strength bin. Regression analysis using the Enertech 89 school dataset (see Figure 9.4) gives *N_dl_cls_in_dl_schl* (classrooms) = 3.8**Bmax* (mG) + 1.4 [R^2=.38].
$Mean\_dl\_fld\_non\_bmax_i$ = mean field in non-Bmax classrooms, for the i^{th} field strength bin of Bmax. Regression analysis using Enertech 89-school dataset (see Figure 9.5) gives *Mean_dl_fld_non_bmax* (mG) = .29**Bmax* (mG) + .49 [R^2=.71]

Then the time-weighted population exposure for non-Bmax classrooms is:

$$Xnonmax = P_{sa} * \sum_i Mean\_dl\_fld\_non\_bmax_i * (N\_dl\_cls\_in\_dl\_schl_i - 1) * Ndlbin_i \qquad \textit{Eqn. 4.9}$$

And, the time-weighted population exposure for Bmax classrooms is:

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[5] Frequency density has units of percent per milligauss, so (for instance) the integral of the frequency density from 1 mG to 2 mG gives the fraction of all distribution line classrooms with 50% fields between 1 and 2 mG.

[6] In 89 schools, the Enertech study identified 20 distribution lines creating a classroom field of 0.5 mG or above. So among the 7700 schools in California, we would expect 20*7700/89 = 1730 of them to have distribution line classrooms. Using the rationale presented in Section 9.3, we estimate that the maximum classroom 50% source field among the 1730 schools with distribution line classrooms is roughly 10 mG.

$$Xbmax = P_{sa} * \sum_i B_i * Ndlbin_i \qquad \textit{Eqn. 4.10}$$

Population exposure reductions resulting from field strength standards applied to distribution lines are computed by summing exposure reduction in Bmax and non-Bmax classrooms. Exposure reduction in Bmax classrooms is whatever is needed to bring the classroom exactly into compliance with the standard. Population exposure reduction in Bmax classrooms is given by:

$$\Delta Xbmax = P_{sa} \sum_{i=Bstnd}^{Bmax\_max} (B_i - B_{Stnd}) * Ndlbin_i \qquad \textit{Eqn. 4.11}$$

where

$\Delta Xbmax$ = population exposure reduction in Bmax classrooms (in person-mG)
P_{sa} = number of persons per classroom of school type *s* and age group *a*
B_{max_max}= maximum distribution line field in any California classroom (assumed to be 10 mG)
B_{stnd} = magnetic field standard (mG)
B_i = mean magnetic field of i^{th} field strength bin
$Ndlbin_i$ = number of distribution lines in California producing Bmax fields in the i^{th} field strength bin (defined previously).

Exposure reduction is non-Bmax classrooms is estimated by assuming that fields in non-Bmax classrooms are reduced by the same proportion as fields in Bmax classrooms. Population exposure reduction in non-Bmax classrooms is given by:

$$\Delta X_{non\text{-}bmax} = X_{nonmax} * \text{F\_nc\_dl\_bmax\_x\_elim} * \text{F\_nonmax\_dl\_cr\_reduc} \qquad \textit{Eqn. 4.12}$$

where

F_nc_dl_bmax_x_elim = $\Delta Xbmax$ / *Xbmax* is the fraction of distribution line population exposure in non-complying Bmax classrooms that is eliminated by the field strength standard. We assume that non-Bmax classrooms that are affected by the distribution line will have the same proportional reduction in total exposure as the Bmax classrooms that are out of compliance.[7]

F_nonmax_dl_cr_reduc = N_nonmax_dl_cr_gt_st / N_nonbmax_dl_clsrms is the ratio of the number of non-Bmax classrooms with field reductions to the total number of non-Bmax classrooms. The number of non-Bmax classrooms with field reductions, *N_nonmax_dl_cr_gt_st,* is simply the number non-Bmax classrooms with 50% source fields exceeding the standard. The total number of non-Bmax classrooms, *N_nonbmax_dl_clsrms,* is the total number of distribution line classrooms minus the number of Bmax classrooms.

[7] For some techniques to reduce fields from powerlines, the field reduction factor (FRF=ratio of post-mitigation to pre-mitigation field strength) varies with distance from the power line. For example, raising line height has only about 70% of the reduction effect at one line-height distance as it does directly beneath the line. EMF_SCHOOL ignores this variation and applies the same FRF to all classrooms affected by the line, regardless of their distance from the line. This simplification results in only small errors in exposure reduction estimates, however, because the bulk of the exposure reduction for any given power line modification occurs in those classrooms that are closest to the line, where the FRF is, by definition, accurate.

4.2.4 Transmission Line Exposure Submodule

The transmission line submodule parallels the distribution line model in all detail. We define a "transmission line classroom" as any classroom that has a transmission line field of at least 0.5 mG in 50% or more of the classroom area. Unlike fields from net currents and electrical panels in classrooms, which change greatly from one side of the classroom to another, fields from transmission lines in classrooms are much more uniform. Therefore, the 95% classroom field and 50% classroom fields from transmission lines aren't much different. In the Enertech 89 school database, for instance, the 95th percentile classroom field from transmission lines is only 24% greater, on average, than the 50th percentile classroom field. Given this modest difference, EMF_SCHOOL computes exposure and exposure reduction from transmission lines using only the 50% source field.

Transmission lines can affect more than one classroom per school. We define the "Bmax classroom" for a particular school as the classroom with the highest field level from that line. "Non Bmax classrooms" are all other transmission line classrooms with transmission line fields that exceed 0.5 mG. Population exposures to transmission lines are computed in two parts: those occurring in Bmax classrooms, and those occurring in non-Bmax classrooms. The reason for making this distinction is that requirements for field strength reduction are determined by field levels in only Bmax classrooms, since those classrooms represent the highest field levels from a given transmission line.

Transmission line population exposure is estimated as follows. Using the Enertech 89 school dataset, we find that the frequency density[8] of transmission lines affecting classrooms (e.g., produce 50% > 0.5 mG in at least one classroom) as a function of classroom average field strength is approximately $1/X^{Amax}$, where X is field strength in milligauss and A_{max} ~ 1.55. This frequency density function is applied up to a maximum plausible transmission line classroom field of B_{max_max} = 20 mG.[9] Integrating this distribution, we find the fraction of transmission lines for which Bmax is in the i^{th} field strength bin, B_i, (each of which is .5 mG wide):

$$f\_bmax_i = \frac{(B_i + .5)^{1-A\max} - B_i^{1-A\max}}{B_{\max\_\max}^{1-A\max} - .5^{1-A\max}} \qquad \textit{Eqn. 4.13}$$

Let

f_schls_w_tl_clsrm = fraction of schools with at least one "transmission line classroom." From the Enertech 89 school data, this parameter is estimated to range from .037 to .077, with a most likely value of .057.

T_lines_per_tl_schl = average number of transmission lines per transmission line school, estimated to be 1.1 from the Enertech dataset.

Nschls = number of schools in California.

Then, the number of transmission lines producing 50% sources fields > 0.5 mG in at least one classroom is:

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[8] See footnote 5.

[9] In Enertech's measurements at 89-schools, there are 9 transmission lines creating a classroom field of 0.5 mG or above. Using Enertech's base weights, these 9 schools represent about 445 schools statewide, or 6% of the 7700 public schools statewide. Using the rationale presented in Section 9.4, we estimate that the maximum classroom 50% source field among the 450 schools with transmission line classrooms > 0.5 mG is roughly 20 mG.

$$Ntl = Nschls*f\_schls\_w\_tl\_cls*T\_lines\_per\_tl\_sch \qquad \text{Eqn. 4.14}$$

And, the number of transmission lines producing Bmax fields in the i^{th} field strength bin is:

$$Ntlbin_i = f\_bmax_i * Nschls * f\_schls\_w\_tl\_clsrm \qquad \text{Eqn. 4.15}$$

Let

$N\_tl\_cls\_in\_tl\_schl_i$ = mean number of transmission line classrooms per transmission line with Bmax in the i^{th} field strength bin. Regression analysis using the Enertech 89-school dataset (see Figure 9.8) gives $N\_tl\_cls\_in\_tl\_schl$ (classrooms)= 3.4*Bmax(mG) - 0.72 [$R^2 = 0.54$].

$Mean\_tl\_fld\_non\_bmax_i$ = mean field in non-Bmax classrooms, for the i^{th} field strength bin of Bmax. Relative to the transmission line, we assume that non-Bmax classrooms are uniformly distributed between the location of the Bmax classroom and the distance at which transmission line fields become negligible (i.e., 50% source field < 0.5 mG). Given that magnetic fields from transmission lines fall off with the inverse square of the distance from the line, one can show that the average non-Bmax classroom field between the location of the Bmax classroom and the distance at which transmission line fields fall to 0.5 mG is $Mean\_tl\_fld\_non\_bmax_i = [0.5*Bmax_i]$^$0.5$.

Then the time-weighted population exposure for non-Bmax classrooms is:

$$Xnonmax = P_{sa} * \sum_i Mean\_tl\_fld\_non\_bmax_i * (N\_tl\_cls\_in\_tl\_schl_i - 1) * Ntlbin_i \qquad \text{Eqn. 4.16}$$

And, the time-weighted population exposure for Bmax classrooms is:

$$Xbmax = P_{sa} * \sum_i B_i * Ntlbin_i \qquad \text{Eqn. 4.17}$$

Population exposure <u>reductions</u> resulting from field strength standards applied to transmission lines are computed by summing exposure reduction in Bmax and non-Bmax classrooms. Exposure reduction in Bmax classrooms is whatever is needed to bring the classroom exactly into compliance with the standard. Population exposure reduction in Bmax classrooms is given by:

$$\Delta Xbmax = P_{sa} \sum_{i=Bstnd}^{Bmax\_max} (B_i - B_{Stnd}) * Ntlbin_i \qquad \text{Eqn. 4.18}$$

where

$\Delta Xbmax$ = population exposure reduction in Bmax classrooms (in person-mG)

P_{sa} = number of persons per classroom of school type *s* and age group *a*

B_{max_max}= maximum transmission line field in any California classroom (assumed to be 10 mG)

B_{stnd} = magnetic field standard (mG)

B_i = mean magnetic field of i^{th} field strength bin

$Ndlbin_i$ = number of transmission lines in California producing Bmax fields in the i^{th} field strength bin (defined previously).

Exposure reduction is non-Bmax classrooms is estimated by assuming that fields in non-Bmax classrooms are reduced by the same proportion as fields in Bmax classrooms. Population exposure reduction in non-Bmax classrooms is given by:

$$\Delta X_{non\text{-}bmax} = X_{nonmax} * \text{F\_nc\_tl\_bmax\_x\_elim} * \text{F\_nonmax\_tl\_cr\_reduc} \qquad \text{Eqn. 4.19}$$

where

F_nc_tl_bmax_x_elim = Δ*Xbmax* / *Xbmax* is the fraction of transmission line population exposure in non-complying Bmax classrooms that is eliminated by the field strength standard. We assume that non-Bmax classrooms that are affected by the transmission line will have the same proportional reduction in total exposure as the Bmax classrooms that are out of compliance.[10]

F_nonmax_tl_cr_reduc = N_nonmax_tl_cr_gt_st / N_nonbmax_tl_clsrms is the ratio of the number of non-Bmax classrooms with field reductions to the total number of non-Bmax classrooms. The number of non-Bmax classrooms with field reductions, *N_nonmax_tl_cr_gt_st*, is simply the number non-Bmax classrooms with 50% source fields exceeding the standard. The total number of non-Bmax classrooms, *N_nonbmax_tl_clsrms*, is the total number of transmission line classrooms minus the number of Bmax classrooms.

A list of sub-model parameters and their values is provided in Table 4.3. See Appendix A for data from which these values are derived.

Table 4.3.Values of key parameters in submodule for transmission line exposure. Values are derived from the Enertech 89-school database.

Parameter	Description	Value	Reference
A_max	Exponent on frequency distribution for fraction of Bmax classrooms in which 50% t-line source field is > X mG.	1.55 +/- .05	Figure 9.7
Bmax_max	Maximum credible transmission line field in classroom anywhere in California. Bmax for transmission line schools is distributed with median 1.8 mG, GSD=2.5. There are several hundred schools with transmission line fields exceeding 0.5 mG in classrooms.	20 mG	Extrapolation from Enertech data for 10 schools with transmission line fields exceeding 0.5 mG in classrooms
frac_schls_w_tl_cls	Fraction of schools with at least one classroom with 50% transmission line field > 0.5 mG. In the Enertech 89 school database, there are nine schools with > 0.5 mG transmission line fields in at least one classroom. Using the base weights for these schools, they comprise 445/7859 = .057 of all California public schools. Uncertainty is assigned based on alternative weightings.	.057 +/- .020	Enertech database
T_lines_per_tl_schl	Number of transmission lines per transmission line school	1.1	Enertech database
N_tl_cls_in_tl_schl	Number of transmission line classrooms in a transmission line school, as a function of Bmax	3.422*Bmax-0.7234 (R^2 = .54)	Figure 9.8
Mean_tl_fld_non_bmax	Mean transmission line field in non-Bmax classrooms, as a function of Bmax.	.36*Bmax	Figure 9.9

[10] See footnote 7.

4.3 Health Effects Module

The Health Effects Module converts estimates of population exposure reduction from the Exposure Module into morbidity and mortality savings for 21 conditions that are possibly related to 60 Hz magnetic field exposure. A summary of the evidence linking these 21 conditions to 60-Hz magnetic field exposure and listing background morbidity (incidence) and mortality rates for these conditions can be found in an earlier report from this project (Sheppard, Kelsh et al. 1998). The 21 conditions included in our policy model are listed in Table 4.4.

Table 4.4. Untoward health outcomes included in EMF_SCHOOL model.

All leukemia	Prostate cancer, m	Amyotrophic lateral sclerosis
Hodgkin's disease	Lung cancer	Alzheimer's disease
Non-Hodgkin's lymphoma	Testicular cancer	Cardiac arrhythmia
Brain/CNS tumor	Melanoma	Coronary heart disease
Breast cancer, female & male	Spontaneous abortion	Major depression
Wilm's tumor	Perinatal mortality	Suicide
Neuroblastoma	Low birthweight	Headache

For each of the conditions in Table 4.4, EMF_SCHOOL estimates EMF effects for five different age groups: Pre-school (ages 2-5), elementary school (ages 6-11), mid/high school (ages 12-17), young adult (ages 18-45), and older adult (46-65). Ages older than 65 are not included because 65 is assumed to be the retirement age for school staff. These age groups different somewhat from those adopted in Sheppard et al 1998. Data in that reference were linearly interpolated to estimate age-specific background morbidity and mortality rates for use in EMF_SCHOOL.

Because each of the diseases in Table 4.4 can be expected to have a different latency period (i.e., period between when EMF exposure is reduced and the time at which health effects actually begin to decline. EMF_SCHOOL includes a latency period for each disease, and discounts future disease reductions using a separate discount rate for risk reduction, which can be set by the user.

A summary of values used in the model for background morbidity and mortality rates as well as latency period is shown in Table 4.5.

Table 4.5. All-cause rates of morbidity and mortality for 21 conditions possibly related to EMF exposure. The five age groups used in the model have been collapsed into two groups (students and staff) for more compact presentation.

Disease	Annual morbidity (cases per 100,000)		Annual mortality (deaths per 100,000)		Latency period (yrs)	
	Students	Staff	Students	Staff	Students	Staff
Spontaneous abortion	0	0	220	800	0	0
Low birthweight	50	200	0	0	0	0
Perinatal mortality	n.a.	n.a.	5.3	25	0	0
Suicide	n.a.	n.a.	2.2	15.4	0	0
Leukemia	3.3	8.9	1.7	52	3	5
Coronary heart disease	0.1	700	0.01	72	0	0
Lung cancer	0.04	70	0	48	0	20
Cardiac arrythmia	1.0	12	0.1	3.5	0	0
Brain/CNS	2.4	6.9	0.61	5.2	3	20
Alzheimers	0	70	0	.45	n.a.	20
Breast (f)	0.01	80	0	16	3	10
Non-Hodgkins Lymphoma	1	17	0.22	5.4	3	5
Unipolar major depression	50	320	n.a.	n.a.	0	0
Hodgkins	1.4	2.9	0.13	0.62	3	5
Melanoma	0	60	0	3.0	n.a.	30
Prostate cancer	0	50	0.01	4.2	n.a.	20
ALS	0.025	1.3	0.025	1.3	5	0
Wlims Tumor	0.2	0	0.01	0	1	n.a.
Breast (m)	2.0	0.4	0	0.07	3	10
Testicular cancer	0.35	3.0	0	0.15	5	10
Neuroblastoma	0.002	0	0.001	0	1	n.a.

4.3.1 Dose metric

Human exposures to power-frequency magnetic fields vary by the minute, hour, day, week, and season. Some scientists have noted that biological responses to magnetic field exposures might depend on some dynamic feature of exposure, or might occur only above some intensity threshold or within some intensity window (Morgan and Nair 1992). Such hypotheses remain highly speculative, however. We use time-weighted average (TWA) field level as the only exposure measure in our model for the following reasons:

- TWA exposure is significantly correlated with risk in the EMF epidemiologic literature (Greenland, Sheppard et al. 2000). See main report for discussion of this point.

- There are scant data relating human risk to any particular non-linear measures of dose. Existing positive epidemiologic studies use only wire code, spot measurements, and/or computed time-averaged power line fields. Without better information to allow us to discriminate between one dose metric and another, we feel that there is little to be gained by modeling arbitrary non-linear metrics.

- Data are not available for characterizing the time history of individual exposures in schools. So even if one wanted to use a dose measure that contained a threshold or some dynamic feature, it would not be possible with current data.

Although we use only TWA exposure in our model, we account for the possibility of other dose measures by including a factor that allows users to degrade the calculated effectiveness of mitigation measures (estimated using TWA), based on the extent to which users judge the true dose metric to be unrelated to TWA magnetic field exposure. For instance, if users judge the correlation between TWA exposure and the "true" dose measure to be only 50%, then the risk reduction attributed to a given exposure standard will be reduced by half from what would be estimated using TWA.

4.3.2 Dose-response for schooltime exposures

All disease conditions that are possibly related to EMF exposure are also caused by other non-EMF factors. The population risk (e.g., incidence rate) for a given condition is the sum of non-EMF and EMF components:

$$R_{total} = R_o + R_{emf} \qquad \textit{Eqn. 4.20}$$

where R_o and R_{emf} are population risks from EMF and other causes, respectively. Assuming a multiplicative[11] model of EMF risk (i.e., that EMF risk is proportional to non-EMF risk), we have

$$R_{total} = R_o + k\ B\ R_o = R_o\ (1 + k\ B) \qquad \textit{Eqn. 4.21}$$

where B is a population magnetic field exposure level and *k* is a dose-response coefficient. Because so much of the epidemiological literature on EMF uses relative risk to describe the slope of the dose-response curve, the school policy model uses as its dose-response parameter the relative risk of chronic exposure to a time-weighted average field of 2 mG compared to the risk of no EMF exposure. This relative risk, RR_2, is related to the dose-response coefficient, *k*, as follows:

$$RR_2 = (R_o + k\ 2\ R_o) / R_o = 1 + 2\ k \qquad \textit{Eqn. 4.22}$$

Or, solving for *k*

$$k = (RR_2 - 1) / 2 \qquad \textit{Eqn. 4.23}$$

If B_{avg} is a suitably-averaged background EMF exposure in a population, then the background disease risk in the population (from both EMF and non-EMF causes) will be:

$$R_{bg} = \quad R_o\ (1 + k\ B_{avg}) \quad = R_o\ [1 + B_{avg}(RR_2 - 1) / 2] \qquad \textit{Eqn. 4.24}$$

Given RR_2, the background population risk, R_{bg}, and the background population exposure, B_{avg}, we can obtain the non-EMF component of population risk, $R_{o:}$

$$R_o = R_{bg} / [1 + B_{avg}(RR_2 - 1) / 2] \qquad \textit{Eqn. 4.25}$$

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[11] EMF risk can be modeled as either proportional to background non-EMF risks (i.e., $R_{emf} = k1*B*R_0$, where *B* is TWA exposure and R_0 is the risk of a given condition from non-EMF causes) or as independent of non-EMF risk (i.e., $R_{emf} = k2*B$). Whether the risk model is proportional or independent doesn't affect the estimated size of EMF effects, unless one is interested in the effect on EMF risk of changes in non-EMF risk. Here, however, we assume that non-EMF risks are constant. The proportional model has the advantage that the algebra is simpler when dealing with relative risks.

EMF risk, R_{emf}, can be decomposed into school and non-school components[12]:

$$R_{emf} = R_{emf\text{-}s} + R_{emf\text{-}ns} \qquad \textit{Eqn. 4.26}$$

If B_s and B_{ns} are the population and TWA magnetic field exposure from all sources in school and non-school environments, respectively, then we have

$$R_{emf\text{-}s} = k\ R_o\ f_s\ B_s \qquad \textit{Eqn. 4.27}$$

$$R_{emf\text{-}ns} = k\ R_o\ f_{ns}\ B_{ns} \qquad \textit{Eqn. 4.28}$$

where f_s and f_{ns} are the fraction of time people are engaged in school and non-school activities.[13]

Substituting the above expression for *k (Eqn. 4.23)* into Equation 4.27, the pre-mitigation disease risk attributable to all sources of EMF in schools combined is

$$R_{emf\text{-}s} = (RR_2 - 1)\ f_s\ B_s\ R_T / [2+B_{avg}\ (RR_2 - 1)\ ] \qquad \textit{Eqn. 4.29}$$

The change in EMF risk resulting from a reduction in TWA schooltime magnetic field exposure (keeping non-school exposure constant) is

$$\Delta R_{emf} = k\ R_o\ f_s\ \Delta B_s \qquad \textit{Eqn. 4.30}$$

Substituting the above expressions for *k (Eq. 4.21)* and R_o (Eq. 4.23) gives

$$\Delta R_{emf\text{-}s} = (RR_2 - 1)\ \ R_{bg}\ f_s\ \Delta B_s / [2 + B_{avg}(RR_2 - 1)] \qquad \textit{Eqn. 4.31}$$

The model assumes that EMF risks from schooltime exposure, if they are real, are proportional to time-weighted average schooltime exposure for both individuals and for populations. To allow for the wide range in beliefs concerning the likelihood that environmental levels of EMF are, in fact, hazardous, we multiply the EMF risk reduction, $\Delta R_{emf\text{-}s,}$ by a factor, p, representing the user's judgment concerning the degree of certainty that EMF exposure is harmful. Furthermore, to account for the possibility that the real dose metric is not proportional to time-weighted average EMF exposure, we also multiply EMF risk reduction, $\Delta R_{emf\text{-}s,}$ by a factor, ε, representing the user's judgment of the actual efficacy of mitigation compared to the efficacy that would be estimated using a TWA dose-response model. The resulting expression for schooltime EMF risk reduction from mitigation is:

$$\Delta R_{emf\text{-}s} = p\ \ \varepsilon\ \ (RR_2 - 1)\ \ R_{bg}\ f_s\ \Delta B_s / [2 + B_{avg}(RR_2 - 1)] \qquad \textit{Eqn. 4.32}$$

Equation 4.32 is the expression used in the school policy model to compute the risk reduction associated with a given magnetic field standard. The various parameters are obtained as follows:

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[12] The EMF_SCHOOL model assumes that school-time and home-time exposures are independent. There may, in fact, be a some correlation between the two, if persons in neighborhoods with lower socio-economic status have higher-than-average magnetic field exposures at both school and at home. We have not analyzed this possibility.

[13] Children spend about 6.5 hours per day at school, for roughly 180 days per year. That's about 13-14% of their total time. Teachers and staff spend somewhat more time at school, perhaps 8 hours per day, 200 days per year, or about 18% of their total time.

p, the degree of certainty (or probability) that EMF causes a particular disease, is the product of two factors: (1) the probability that EMF at levels encountered in schools causes disease of ANY type, and (2) the conditional probability that EMF causes the particular disease in question, given that it causes disease of any type. In the current version of the model, the first of these factors is selectable by the user with the following values available: 0, 0.03, 0.1, 0.3, 1.0. The second of these factors is by default set at 1.0 for all diseases, but this can be altered by the user by editing the model's disease data table.

ε, the ratio of the real efficacy of mitigation to that computed using a TWA exposure measure, is selectable by the user. The following values are available: 0.03, 0.1, 0.3, 1.0

RR_2, the relative risk of chronic (i.e., 24/7) exposure to 2 mG compared to zero exposure is selectable by the user from a range of values: zero risk (RR_2=1.0), undetectable risk (RR_2 = 1.1), barely detectable risk (RR_2 = 2.0), and easily detectable risk (RR_2 = 5.0). "Detectability" in this context refers to how difficult it is to see an EMF effect of the given size in an typical EMF epidemiologic study.

R_{bg}, the background risk of a given disease, is the morbidity (incidence) or mortality rate for that condition by age group (Sheppard et al., 1998).

f_s, the fraction of time in school, is estimated as follows: pre-school (0.1), elementary, middle and high school (.14), adult staff (.18). This is based on 180 days of school annually for children, with K-12 children attending an average of 7 hours per day, and 185 days of school annually for staff attending an average of 8.5 hours per day. The pre-school fraction is a guess, based on the assumption that pre-school classrooms are not likely to be filled as many hours as K-12 classrooms.

ΔB_s, the change in average population exposure resulting from implementation of an exposure standard, is computed in the exposure submodule as the sum of exposure reductions from each of the four sources (net currents, electrical panels, distribution lines, transmission lines)

B_{avg}, the average magnetic field exposure for the California population as a whole, is derived by taking an average of magnetic field exposure measurements from several studies. Zaffanella and Kalton measured 24-hr personal exposure of 1012 quasi-randomly selected adults and children in the U.S., finding time- and population-average exposures of 1.25 mG (Zaffanella and Kalton 1998). Lee and colleagues (1999) measured the 24-hour personal exposure of 28 public school teachers at two elementary schools in California, one of which was near a 69 kV transmission line (Lee, Reynolds et al. 1999). They report time- and population-average exposures of 0.94 mG, with little difference between the school with and without the transmission line. In another study, Lee and colleagues measured 24-hour personal exposure of California women in conjunction with an epidemiologic study of EMF and spontaneous abortion (Lee, Neutra et al. 2000). 24-hour exposures for the 483 controls in that study averaged 1.43 mG, with worktime exposures averaging 1.99 mG. Zaffanella and Kalton's personal exposure data include some California schoolchildren, but these have not yet been separately analyzed. We will assign B_{avg} = 1.2 mG for adults and B_{avg} = 1.0 mG for school children, on the assumption that children exposures are smaller than adult exposures because children have no worktime exposure. Sensitivity studies show that variations of 0.1 mG either way in Bavg result in a 3% change in the estimated health impact from schooltime EMF.

Note that R_{bg}, f_s, ΔB_s, and B_{avg} are endogenous to the model, whereas p, ε, and RR_2 are subjective factors - comprising beliefs about the likelihood and severity of EMF health risks, and the efficacy of mitigation -

that are input by the user. To make it easier for users to explore the sensitivity of results to these subjective factors, users may select from one or more pre-set values that span the range of plausible values for each factor.

4.3.3 Disability-adjusted life years.

To facilitate comparisons between morbidity and mortality savings, and between different types of morbidity savings, we convert morbidity and mortality savings into savings of disability-adjusted life-years (Murray 1994; Murray and Acharya 1996; Anand and Hanson 1997). The DALY is a concept for combining morbidity and mortality effects into a single index of disease burden. The contribution to DALYs from premature death is the number of years of life-expectancy lost. For the age-groups in our model, these are as given in Table 4.6.

Table 4.6. Disability-adjusted life-years lost assigned to premature mortality as a function of age group. DALYs lost is difference between life expectancy at age of death and age of death.

Age group	Years of life lost (DALYs) from premature mortality (based on life expectancy at age of death)
2-5	73
6-11	68
12-17	62
18-45	46
46-65	25

The disability life-years associated with contracting a particular disease and surviving with it are calculated by multiplying the average years lived with the disease by a disability weight. The durations were obtained from Tables 123 to 249 of Volume II of Global Health Statistics (Murray and Lopez 1996). The disability weights were obtained from Annex Table 3, Volume I of the same publication. Since certain diseases were not listed in these publications, the following substitutions were made by DHS staff on the basis of professional judgments on the suffering and duration occasioned by these diseases.

Table 4.7. Disease substitutions used to assign disability weights to cases of diseases not listed in Murry and Lopez 1996.

Original Disease	Substitution Disease
Hodgkins	Leukemia
Brain cancer	Lung cancer
Wilms tumor	Lung cancer
Neuroblastoma	Lung cancer
Testicular cancer	Prostate cancer
ALS	Parkinsons disease
Alzheimer's disease	Dementia

Table 4.8 shows the number of DALYs that EMF_SCHOOL assigns to each case of a given condition, exclusive of the DALYs associated with premature death, which are given in Table 4.6. Note that spontaneous abortion and perinatal mortality are counted as 75 years of life expectancy lost, but some model users may wish to adjust this downward.

Table 4.8. Disability-adjusted life-years assigned to one case of given condition at given age (exclusive of life-years lost from possible premature mortality)

Disease	Age group				
	2-5	**6-11**	**11-17**	**18-45**	**46-65**
All leukemia	0.2	0.2	0.35	0.4	0.41
Hodgkin's disease	0.14	0.15	0.24	0.27	0.28
Non-Hodgkin's lymphoma	0.27	0.26	0.26	0.23	0.23
Brain/CNS tumor	0.39	0.39	0.39	0.31	0.26
Breast cancer, female	0	0	0.4	0.38	0.36
Breast cancer, male	0	0	0.4	0.38	0.36
Wilm's tumor	0.39	0.39	0	0	0
Neuroblastoma	0.39	0	0	0	0
Prostate cancer	0	0	0	0.63	0.59
Lung cancer	0	0	0.39	0.31	0.26
Testicular cancer	0.64	0.64	0.64	0.63	0.59
Melanoma	0	0	0	0.2	0.19
Spontaneous abortion	0	0	75	75	75
Perinatal mortality	0	0	75	75	75
Low birthweight	0	0	17	17	17
Amyotropic lateral sclerosis	0	1.6	1.6	1.6	1.6
Alzheimer's disease	0	0	0	0	12
Cardiac arrhythmia	0.024	0.024	0.024	0.024	0.024
Coronary heart disease	0.024	0	0.024	0.024	0.024
Major depression	0	0	0.17	0.17	0.17
Suicide	0	0	0	0	0
Headache	0	0	0	0	0

4.3.4 Health-related input data

Disease-specific and age-specific data on the various factors needed for the risk calculations are contained in a single three-dimensional table within EMF_SCHOOL called the "Disease Data Table." This table contains:

- Background morbidity rate (per 100k) for the condition, by age group
- Background mortality rate (per 100k) for the condition, by age group
- Probability that EMF causes the condition, given that it causes any
- Relative risk of chronic 24-hr exposure to 2 mG compared to the risk of zero EMF exposure
- Latency period for the disease (years)
- Disability life-years saved per case avoided

The table Disease data table can be accessed from the EMF_SCHOOL opening panel by clicking on "more inputs" and then the "edit table" button of the "disease data table" bar.

4.4 Health Benefits Valuation Module

The Valuation Module converts estimates of annual savings of DALYs into a present equivalent dollar amount. Current investments in EMF exposure reduction results in a stream of health benefits that begin to accrue after some latency period and extends throughout the physical lifetime of the intervention measure (the lifetime of the school building in most cases). The stream of annual benefits is discounted to account for the fact that a disease case avoided today is valued more than a disease case avoided in the future. We compute a present equivalent health savings (in DALYs), which is the amount of health savings gained today for which one would be indifferent between that health savings and the stream of annual health savings that EMF exposure reduction is estimated to provide. Present equivalent DALYs are converted into dollars using a user-supplied willingness to pay for health savings (e.g., $50,000 per disability-adjusted life-year saved).

4.5 Cost Module

The costs of exposure reduction to meet a given magnetic field standard are estimated separately for each of the four EMF sources in different submodules. Estimates of statewide mitigation costs are based on mitigation cost estimates provided in Zaffanella and Hooper 2000, as well as "CAL," the California School EMF Reduction Cost Program, which extrapolates statewide costs based on cost estimates for 89 schools. CAL finds the least-cost set of field reduction techniques that would be needed to achieve a given field strength target in classrooms.

Although the Enertech data are accurate for the purpose of estimating costs for exposure standards that are well within the range of common field levels (e.g., < 3 mG classroom average), uncertainties rise with increasing field strength, because the 89 school data base contains relatively few cases at higher field levels. To address this problem, we fit probability distributions to data at lower levels, and estimate the number of cases at higher field strengths using the tails of these distributions. The specifics of our cost-estimation sub-model are different for different source types.

Using the CAL computer program from Enertech, we generated a dataset consisting of mitigation cost estimates and possible predictors of mitigation cost for the transmission lines in the 89 school study. These possible predictors included field reduction factor (FRF), the number of power line spans near the school, and line voltage. Next, we did a series of regressions to determine the best fit of possible predictors to the CAL program's cost estimates. For transmission lines, we find that cost per school site is related to field reduction factor (FRF) and transmission line voltage, V (in kV), but not to number of spans, by:

$$\text{Log}_{10}(\text{cost per site in \$}) = .17*\log_{10}(\text{FRF}*\text{V})^2 + 3.6 \qquad [\text{Adjusted } R^2 = .67] \qquad \textit{Eqn. 4.33}$$

EMF_SCHOOL estimates statewide mitigation costs for transmission lines by computing the distribution of field reduction factors required to meet a given standard (by line voltage), and then applying the above regression equation to that distribution of FRF and voltage.

The distribution of mitigation costs for transmission line schools across the state is estimated by inserting distributions for FRF and line voltage into the above regression equation. We use this method rather than the statewide cost totals computed using Enertech's CAL program because the CAL program does not model cases more extreme than those encountered in the Enertech 89 school survey. For a given field standard level, the statewide distribution of FRFs is found by fitting a distribution to the TWA field level in the one classroom (in each school) that is most out of compliance with the standard.

The procedure for estimating distribution line costs is similar to that for transmission lines, except that the regression equation used to compute the distribution of cost per site uses both FRF and the number of spans per site as predictor variables. Using the CAL program to generate least-cost solutions for various field strength targets in schools with distribution line fields in classrooms, we find that the best-fit relationship for the cost per school site for distribution mitigation is related to field reduction factor and number of spans, but not to line voltage, by:

$$\text{Log}_{10}(\text{cost per site in \$}) = 19{,}400*(\text{FRF}*\#\text{ of spans})^{0.152} \qquad [\text{Adjusted } R^2 = .32] \qquad \textit{Eqn. 4.34}$$

Costs for diagnosing and fixing net current problems are estimated using Equation CE5.1 in Zaffanella and Hooper 2000 as well as the data in Cost Table 5.1 of that same report (page 10-66). Triangular distributions[14] are assigned to each of the cost coefficients in Table 5.1.

For electrical panels, costs are estimated using equations CE 4.1 and CE 6.1 on page 10-72 of Zaffanella and Hooper 2000. Triangular distributions are assigned to each of the coefficients in Zaffanella and Hooper's cost tables 6.1 and 6.2. Distributions for height and width of electrical panels are obtained from the Enertech 89-school database.

Because the Enertech cost estimates are uncertain, users of EMF_SCHOOL may adjust the costs computed by the model by setting the model's "mitigation cost multiplier," which simply multiplies the Enertech costs by some factor ranging from 0.1 to 10.

4.6 Policy Performance Module

The policy performance module computes various outcome measures of interest. These include (i) population exposure reduction, expressed in both absolute and relative terms, (ii) morbidity and mortality savings, expressed in both absolute and relative terms, (iii) statewide costs of policy implementation, (iv) the cost-effectiveness of the policy, and (v) the net benefits of the policy, assuming a user-defined value for risk reduction. All results are computed as a function of field standard and various assumptions concerning exposure, dose-response, mitigation cost, and valuation of health impacts.

5. Model Limitations

As mentioned at several points in the preceding text, EMF_SCHOOL contains a number of assumptions. It is important that users be aware of these assumptions, so as not to apply the model results beyond its design domain. In summary, the most important of these assumptions are as follows:

- The model uses average and aggregate values for the state as a whole and cannot be used for any specific school.

- The model assumes that risk is proportional to time-weighted average (TWA) magnetic field exposure. Other dose-response functions, such as one with a field strength threshold, might yield substantially lower benefits of field strength reduction.

- The model assumes that the TWA magnetic field exposure for the student and staff populations as a whole can be approximated by the spatially-averaged field in classrooms (as determined from the Enertech measurements). This assumption works best if students and staff are uniformly distributed within classrooms. As students' seating assignments are commonly shuffled in elementary grades, and as students frequently switch classrooms in upper grades, this assumption would seem to be a good one.

[14] A triangular probability distribution has three parameters: minimum, mode, and maximum. The probability density is zero below the minimum, increases linearly from the minimum to the mode, decreases linearly from the mode to the maximum, and is zero above the maximum.

- The model assumes that classroom exposure is more important than exposures anywhere else on school grounds. Although this assumption works well for a time-weighted average dose-response measure, it would not work well for some other plausible measures. For instance, if EMF effects accrued only for exposures greater than 5 mG, then health effects from power line exposures would be underestimated, since power line fields greater than 5 mG are found predominantly outdoors on the sections of school property that lie closest to the power line.

- The model addresses only four sources: net currents, electrical panels, distribution lines, and transmission lines. Although these four sources contribute 86% of the classroom-average magnetic field level above 0.5 mG statewide, there are other sources that may be important sources of exposure in particular schools. For purposes of exploring the costs and benefits of statewide exposure reduction policies, however, the four sources modeled in EMF_SCHOOL together capture the most important characteristics of all sources combined.

6. Running the model

6.1 Adjusting model speed and performance

The following are some suggestions for adjusting model inputs and Analytica's features for suitable model performance.

The number of Monte Carlo samples used in constructing the probability distributions on the outputs can be changed using the "Uncertainty Options" option of Analytica's "Results" menu. The time needed to complete a computation is proportional to this samplesize. With each input variable set to just one option and samplesize set to 100, it takes about 6 seconds to run a net benefit calculation on a 300 MHz Pentium II machine. The larger the samplesize, the less variation there will be in the results from run to run, and the more accurate will be estimates of the extremes of the distributions of the output variables.

Many of the variables on the control panel screen of the model can be set to just one value, or to a range of values. For instance, "Disease to analyze" can be set to just one disease, or to "all" diseases. The time needed to complete a calculation is proportional to the product of the number of options for each control panel input variable. So a calculation that considers all 21 diseases will take 21 times longer to run than a calculation that considers only one disease. If many variables are set to "all," then it might be necessary to dramatically reduce samplesize to obtain reasonable computation times. Samplesizes less than 10-20 samples, however, will result in significant variability in results from run to run.

7. Model Displays and Example Output

Some example displays and results from the model are presented below.

7.1 Control Panel Screen

When EMF_SCHOOL is launched, the user is presented with the control panel screen shown in Figure 7.1. The top three (yellow, salmon, and green) sections contain buttons that allow the user to set a number of model parameters, as listed in Table 7.1

The bottom (blue) section contains buttons that generate various model outputs. The abbreviation "PE" refers to "present equivalent" values, which are obtained by summing future annual values from the present until the end of the useful lifetime of the mitigation measure, and applying a discount factor.

Clicking on of the blue rounded boxed arrayed vertically on the right side of the top-level screen will open the following:

- Decision model. Clicking on this box will lead the user to the guts of EMF_SCHOOL, through successive submodels to individual variable nodes. Go here if you want to understand in detail how a particular variable is defined or estimated.

- Model description. Clicking on this box will lead the user to text describing each submodule of EMF_SCHOOL (similar to the descriptions in this document).

- More inputs. Clicking on this box will open a supplementary input screen containing nodes for access to the disease data table (with values for background disease rates, relative risk of EMF exposure, and disability-adjusted life-years lost per year of morbidity) and the spatial criteria for the EMF standard (i.e., whether the standard is based on spatially-average EMF levels or the 95th percentile spatial field).

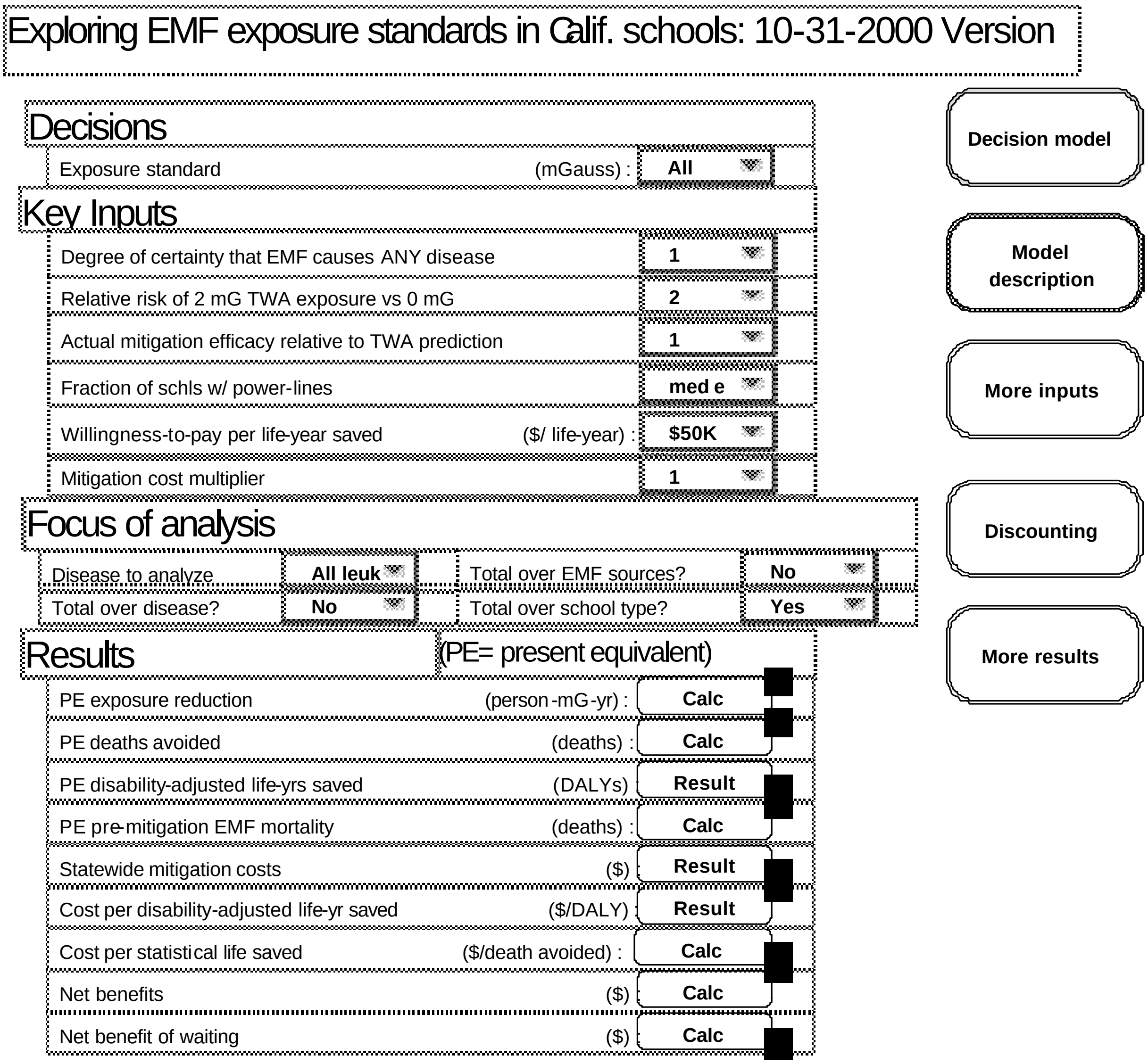
- Discounting. This box contains all the parameters needed to set discounting functions, such as discount rates for money and risk, and the useful lifetime of mitigation measures.

- More results. This box contains buttons for nine outputs not available on the top-level control panel.

Table 7.1.User-setable input parameters on top-level control panel. Choosing the “ALL” option in the list of values causes Analytica to compute results for all of the values listed.

Parameter	**Description**	**Values**
Exposure standard	Field strength standard to be applied in classrooms statewide	0.5, 1, 2, 5 milligauss or ALL
Degree of certainty that EMF causes ANY disease	Probability that magnetic fields are linked to at least one disease in humans	0, .03, 0.1, 0.3, 1.0 or ALL
Relative risk of 2 mG TWA exposure vs 0 mG	Relative risk of 24hr TWA exposure of 2 mG compared to 24hr TWA exposure of 0 mG	1, 1.1, 2, 5 or ALL
Actual mitigation efficacy relative to TWA prediction	Actual efficacy of mitigation relative to what would be predicted if disease risk was proportional to time-weighted average (TWA) magnetic field exposure. The model applies the same mitigation attenuation factor to all EMF-related diseases.	0.03, 0.1, 0.3, 1 or ALL
Fraction of schools w/ power-lines	Fraction of schools with transmission or distribution lines close enough to produce 0.5 mG in at least one classroom. Uncertainty arises from limited samplesize in Enertech 89 school database.	For distribution lines, Low = .11, Medium = .19, High = .27 or ALL. For trans. lines, Low = .01, Medium = .056, High = .10 or ALL
Willingness-to-pay per life-year saved	Willingness to pay to save one disability-adjusted life-year in the present.	$10k, $50k, $250k or ALL
Mitigation cost multiplier	Allows user to adjust Enertech cost estimates for any perceived bias. The actual cost used by this program is Cost = mitigation cost multiplier * Enertech cost estimate The same mitigation cost multiplier is applied to all sources (net currents, electrical panels, dist lines, trans lines).	0.1, 0.3, 1, 3, 10 or ALL
Disease to analyze	Selects for which one of 21 possibly EMF-related diseases the analysis should be computed.	All leukemia, Hodgkin’s disease, Non-Hodgkin’s lymphoma, Brain/CNS tumor, Breast cancer, f, Breast cancer, m, Wilm’s tumor, Neuroblastoma, Prostate cancer, m, Lung cancer, Testicular cancer, Melanoma, Spontaneous abortion, Perinatal mortality, Low birthweight, Amyotrophic lat sclerosis, Alzheimer’s disease, Cardiac arrhythmia, Coronary heart disease, Major depression, Suicide, Headache, Or ALL
Total over disease?	If “yes” results are computed for the sum of all diseases. If “no”, results are presented separately for each disease.	Yes No
Total over EMF sources?	If “yes” results are computed for the sum of all four EMF sources (net currents, electrical panels, distribution lines, transmission lines). If “no”, results are presented separately for each source.	Yes No
Total over school type?	If “yes” results are computed for the sum of all school types (pre, elementary, mid/hi school). If “no”, results are presented separately for each disease.	Yes No

Figure 7.1. Top-level control panel screen for EMF_SCHOOL.



7.2 Present Equivalent Exposure Reduction

The present equivalent exposure reduction is the discounted sum over the lifetime of the mitigation measure of the exposure reductions resulting from a classroom field strength standard.

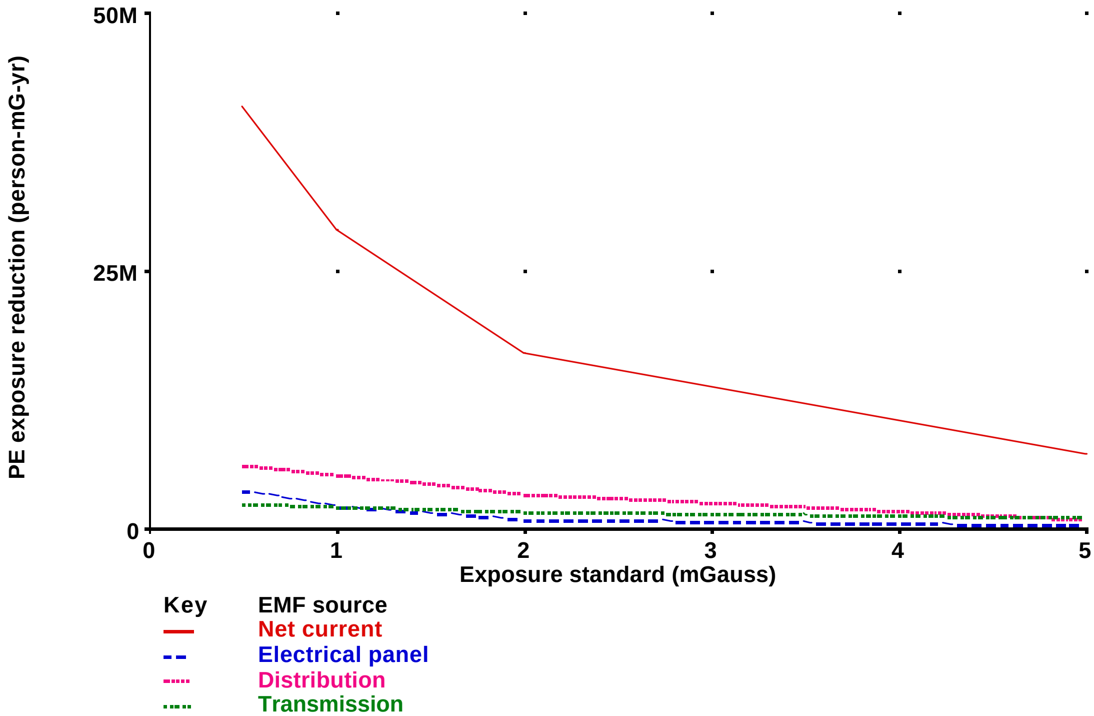


Figure 7.2. Present equivalent exposure reduction for all sources combined, as a function of exposure standard, 30 year useful lifetime of mitigation, 5% discount rate for future exposure savings, fraction of power lines near schools = medium.

7.3 Mortality reduction

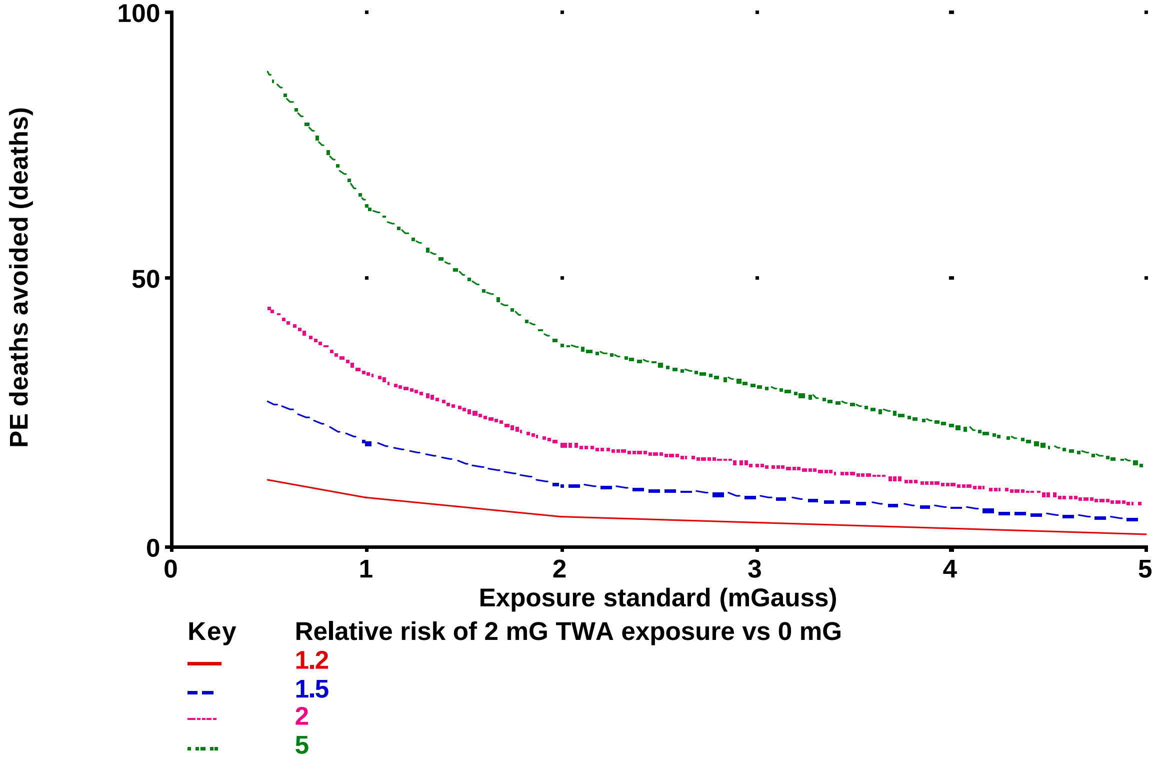


Figure 7.3. Present equivalent of number of student and staff leukemia deaths averted over physical lifetime of mitigation measure, versus classroom exposure standard and relative risk of 2 mG TWA exposure. Results assume 100% certainty that EMF exposure increases disease risk,30 year time horizon, 5% discount rate on risk, 100% mitigation efficacy relative to efficacy predicted by TWA.

7.4 Mitigation costs

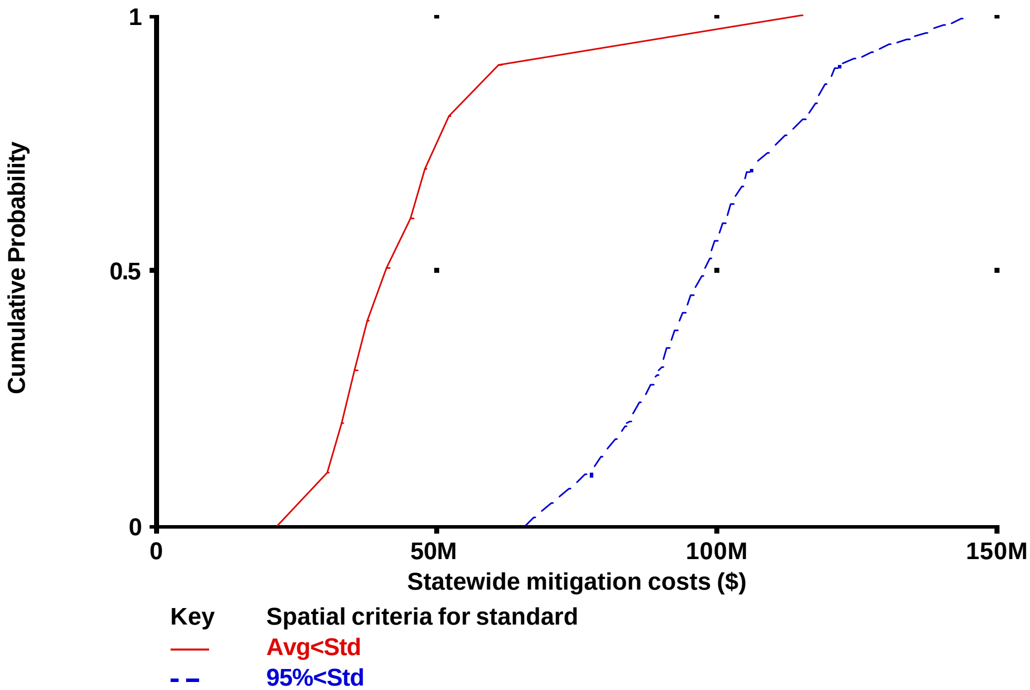


Figure 7.4. Cumulative probability distribution of statewide costs to meet a field strength standard for classrooms of 2 mG for all four EMF sources combined.. Mitigation cost multiplier = 1. Curves for two different targets are shown, (i) spatial average less than standard and (ii) classroom 95th percentile field less than standard.

7.5 Cost per unit risk reduction

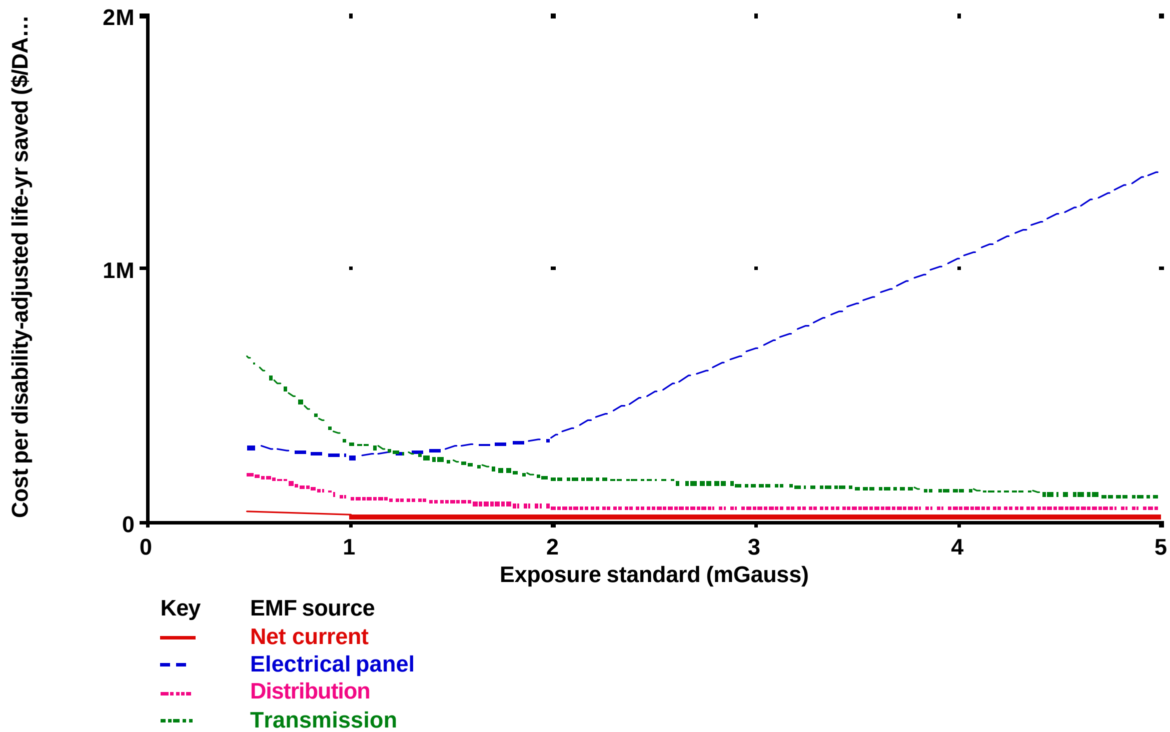


Figure 7.5. Average cost per present equivalent disability-adjusted life-year (DALY) saved to reduce exposure from each of four sources, as a function of exposure standard. Mitigation cost multiplier = 1, 30 year useful lifetime of mitigation, 5% discount factor

7.6 Net Benefits

Net benefits are the discounted sum of the benefits stream over the lifetime of the mitigation, minus the present costs of the mitigation.

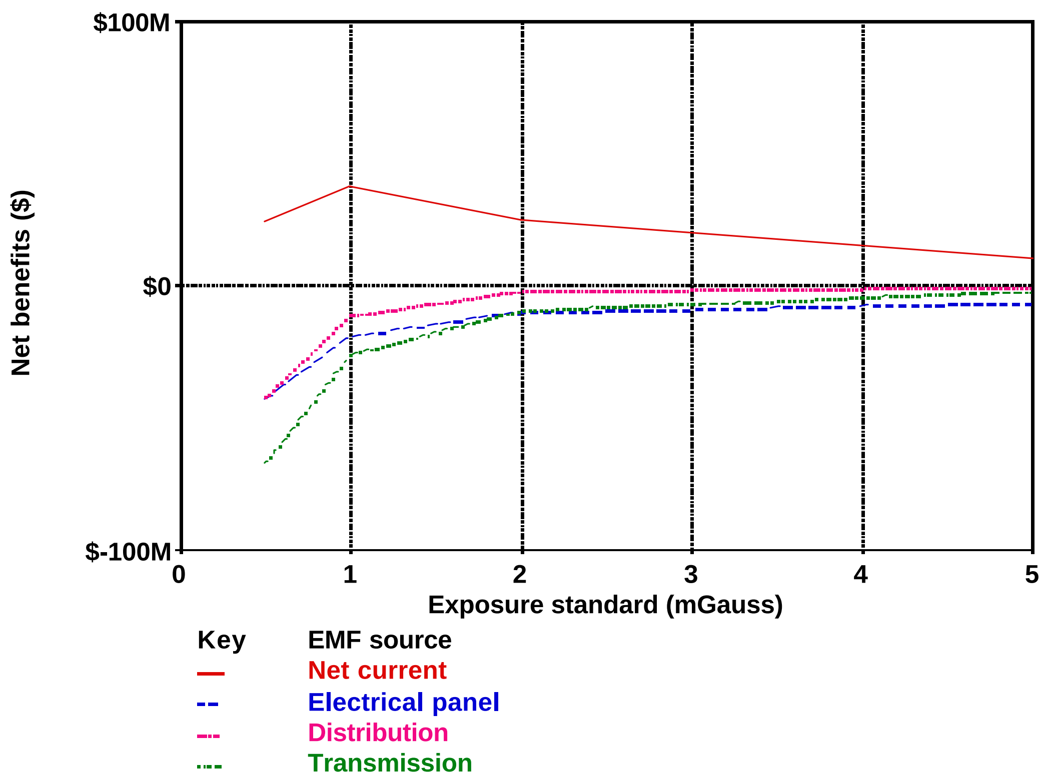


Figure 7.6. Net benefits of exposure standard for classroom average fields addressing four different sources. Assumptions: leukemia only, willingness-to-pay = $50k per life-year, mitigation cost multiplier=1, RR_2=2, Degree of certainty = 1.

8. References

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9. Appendix . Data supporting EMF_SCHOOL calibration

9.1 Calibration of Net Current Submodel

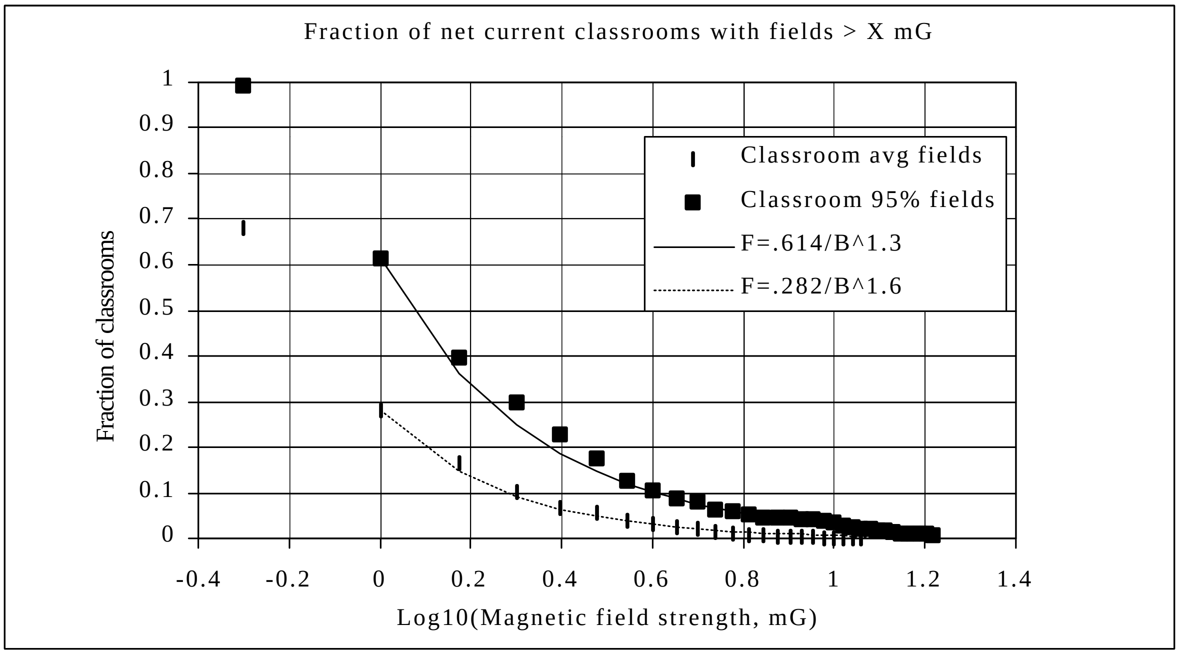

Figure 9.1. Fraction of net current classrooms with spatially averaged and 95th percentile fields greater than X mG. Derived from Enertech 89-school dataset.

9.2 Calibrating Electrical Panel Submodel

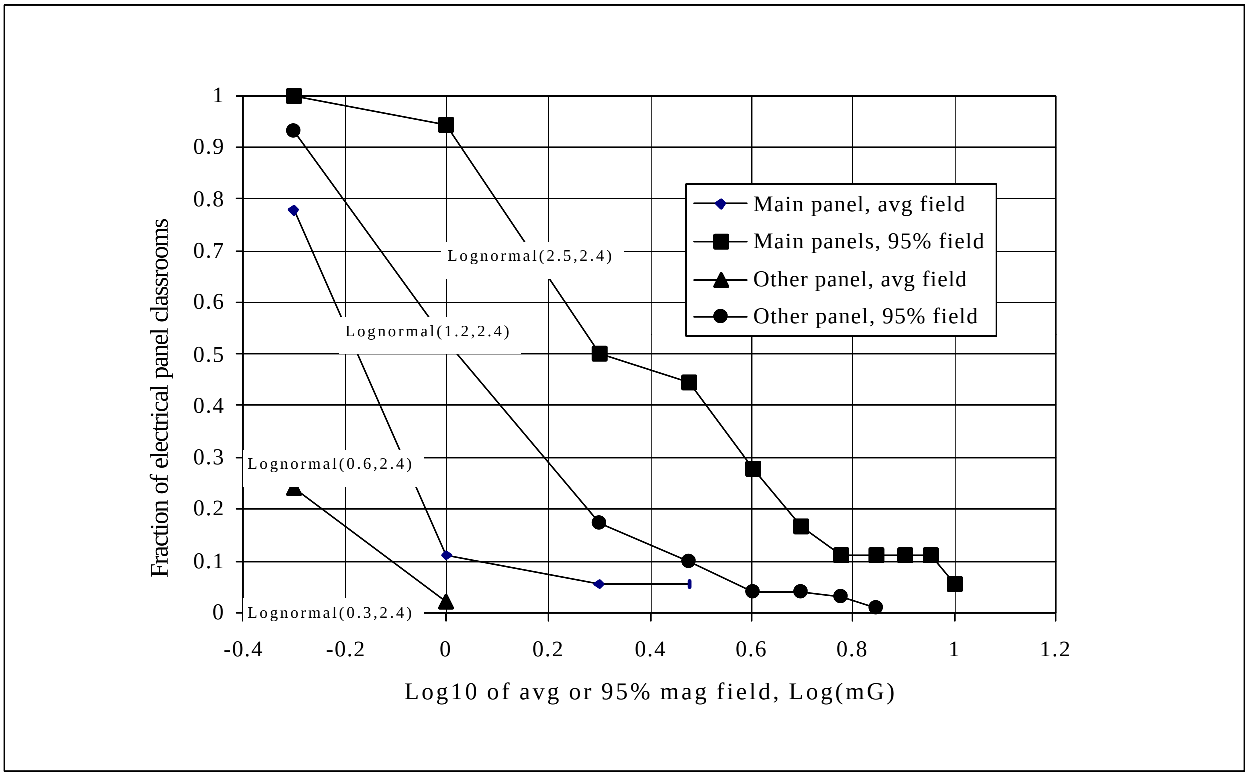

Figure 9.2. Fraction of electrical panel classrooms with average and 95% area fields exceeding specified level. Distributions are approximately lognormal with the specified medians and geometric standard deviations (GSD).

9.3 Calibrating Distribution Line Submodel

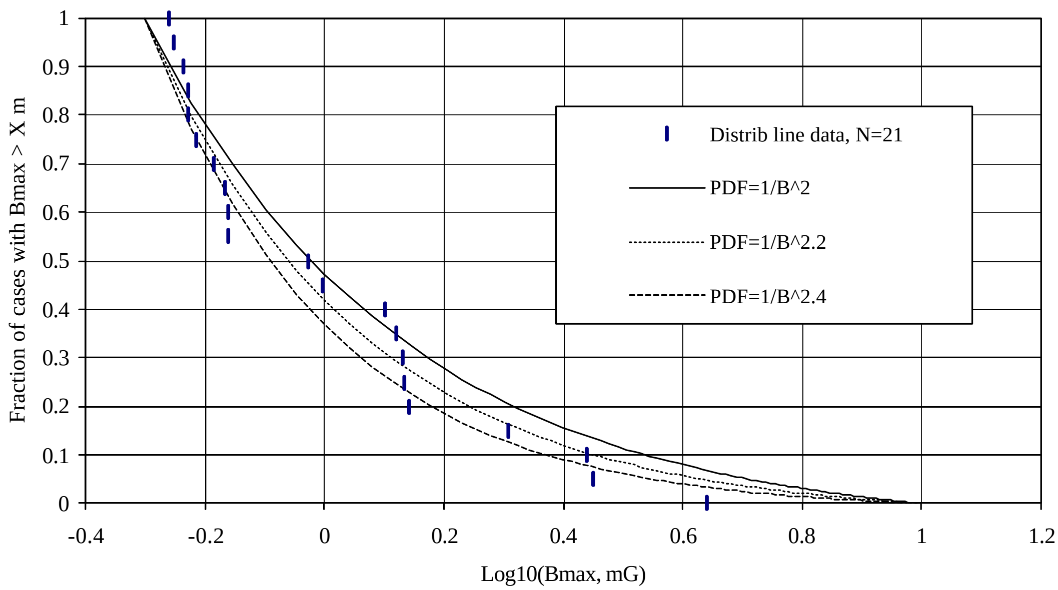

Figure 9.3. Fraction of distrib-line Bmax classrooms in which 50% d-line source field is > X mG, based on Enertech data for 21 distribution lines in 89 school sample. PDF is probability density function from which these cumulative distribution functions are derived by integration.

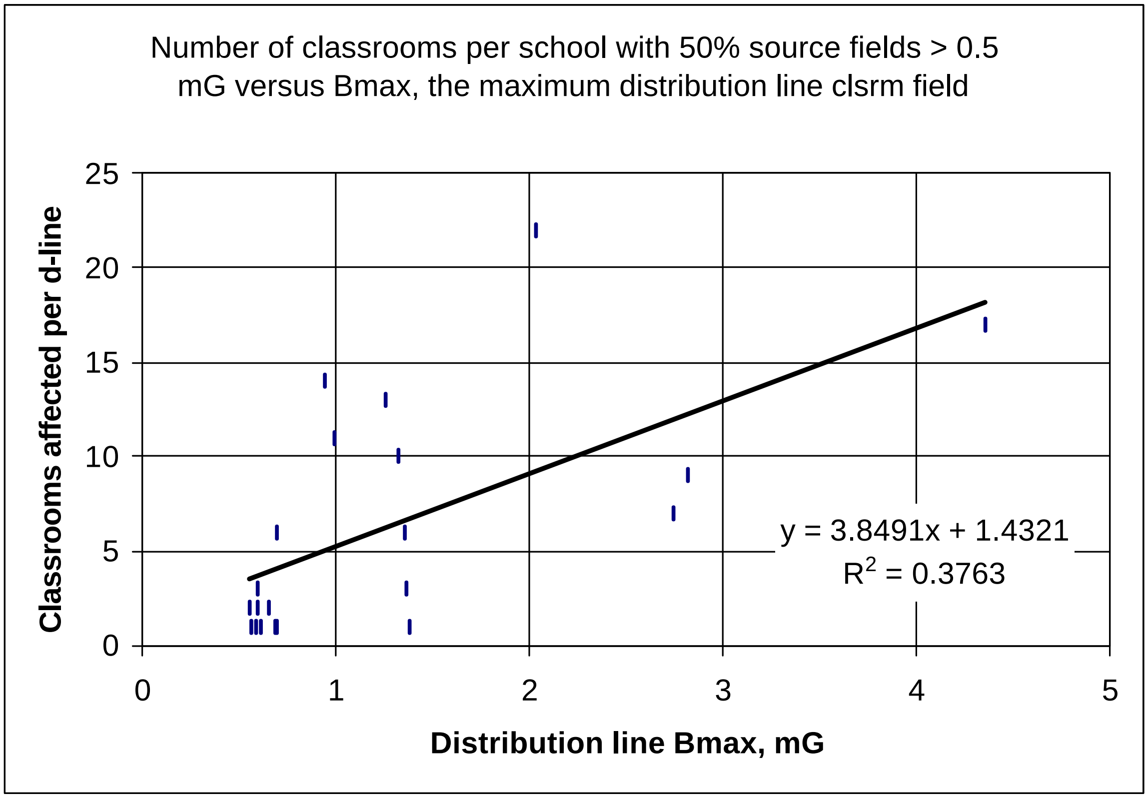

Figure 9.4. Number of classrooms per school with 50% source fields > 0.5 mG versus Bmax, the maximum distribution line classroom field. Derived from the Enertech 89-school dataset.

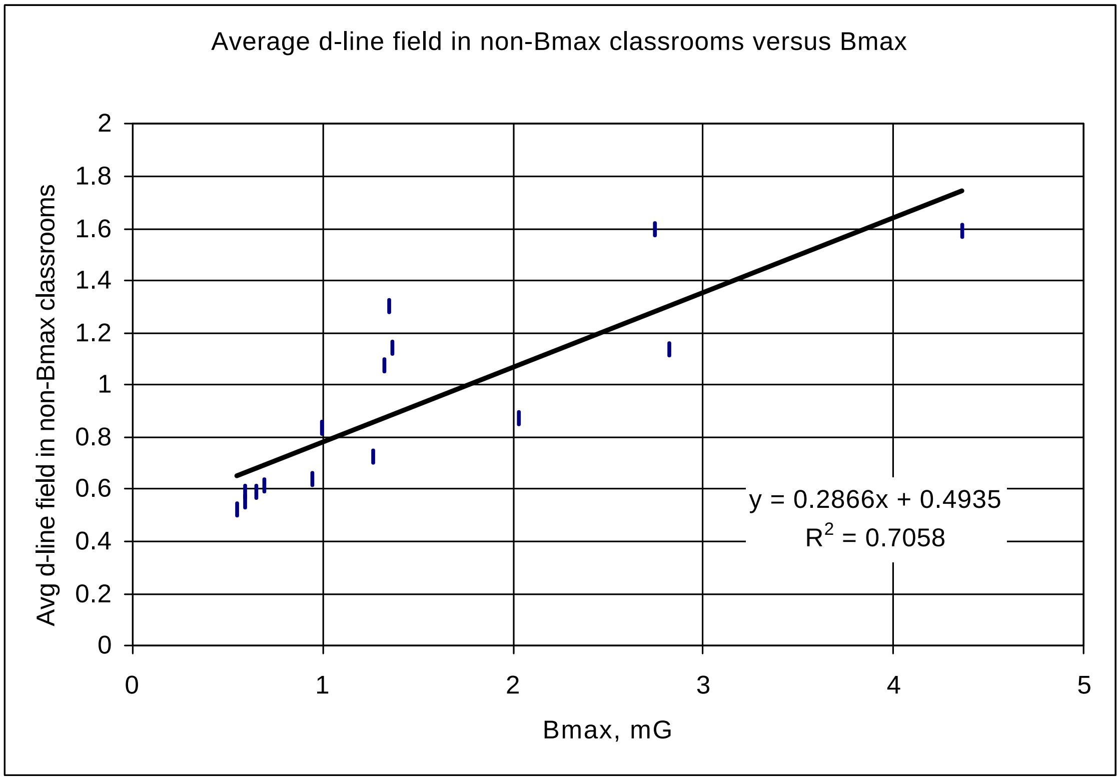

Figure 9.5. Average distribution-line field in non-Bmax classrooms versus Bmax. Derived from Enertech 89-school database.

Estimation of Maximum Credible Classroom Field from Distribution Lines

(See Excel file: Dline Bmax freq distribution)

In the Enertech 89-school sample, there are 128 distribution lines at 75 schools. Only 20 of these lines (16%) produce 50% source fields >=0.5 mG in classrooms.

If D is the distance from the transmission line to the nearest building and H is the line height, then the average field in that building at the point closest to the line will be Bmax (mG) = K_1 / (D+H)^K_2, where K_1 and K_2 are constants that Enertech fit to field profile data for each of the 128 distribution lines. Distances from the 128 distribution lines to the nearest school building are distributed as a half lognormal with a median of 25 feet and a geometric standard deviation (GSD) of 4 (i.e. 95% of distances are less than 25x4x4=400 feet). The field profile coefficient, K_1, for this sample is lognormally distributed with median 400 and a GSD of 7.6. The field profile coefficient, K_2, is highly correlated with K1 (R^2=.60), so we approximate K_2 using a best-fit to K_1 as follows: Log10(K_2) = .126*log10(k1) - .132. The correlation between K_1 and D is only 0.2, suggesting that school buildings in this sample are positioned no further from large distribution lines than from smaller ones. Using these statistical parameters, we constructed a simulated data set for 11,000 schools of line-to-building distance and field profile coefficient, $K_{1.}$ Since the Bmax classroom is not necessarily located on the lineward side of the school building closest to the distribution line, we adjusted the median of the distribution of D so as to produce the same fraction of Bmax classrooms over 0.5 mG in our synthetic sample (16%) as was observed in Enertech's sample. The resulting synthetic distribution is shown below.

Percentiles of synthetic distribution of B_{max} for 11,000 distribution lines near California public schools.

Percentile of 11,000 sample	Bmax, mG
1	0.001
5	0.004
10	0.009
25	0.025
50	0.097
75	0.383
90	0.883
99	1.960
99.9	8.469
max	56.490

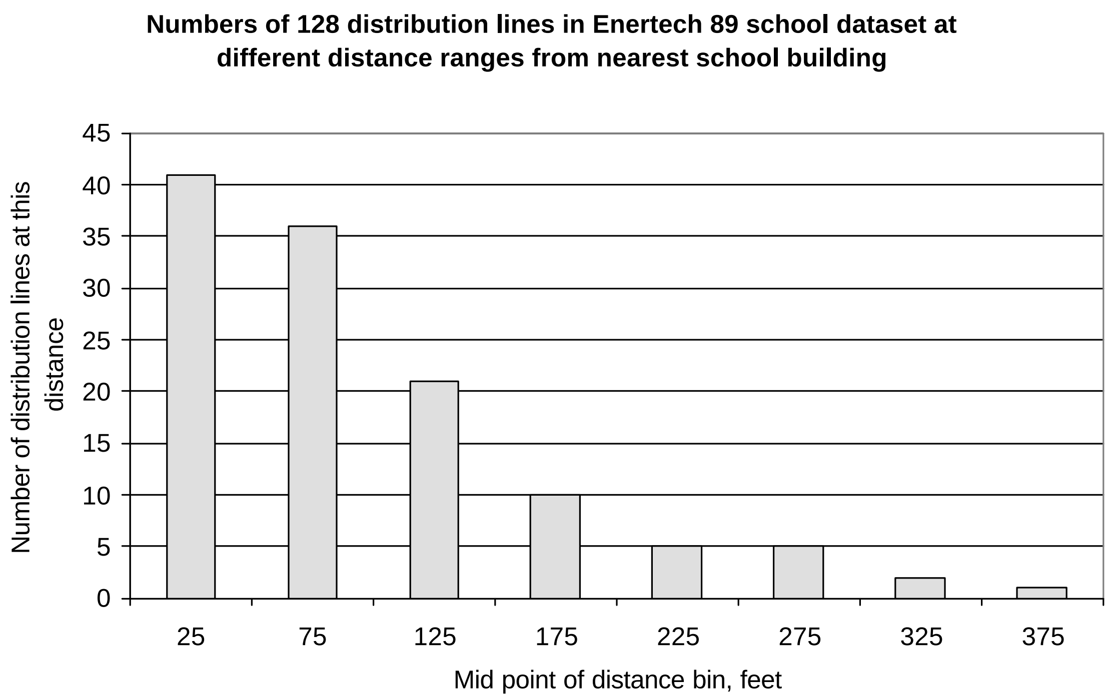

Figure 9.6. Histogram of distribution lines in Enertech 89 school sample arrayed by distance from line to nearest school building.

9.4 Calibrating Transmission Line Submodel

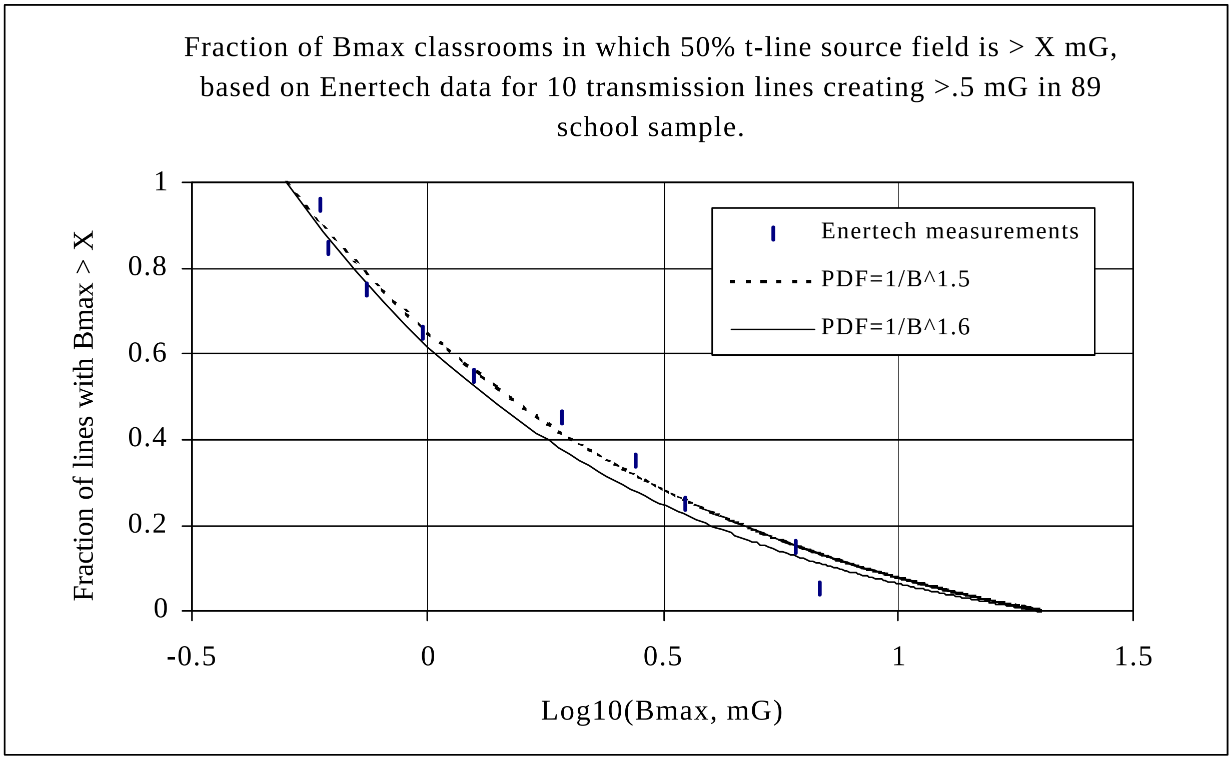

Figure 9.7. Fraction of Bmax classrooms in which 50% transmission-line source field is > X mG, based on Enertech data for 10 transmission lines creating >.5 mG in 89 school sample. PDF is probability density function from which these cumulative distributions are derived by integration.

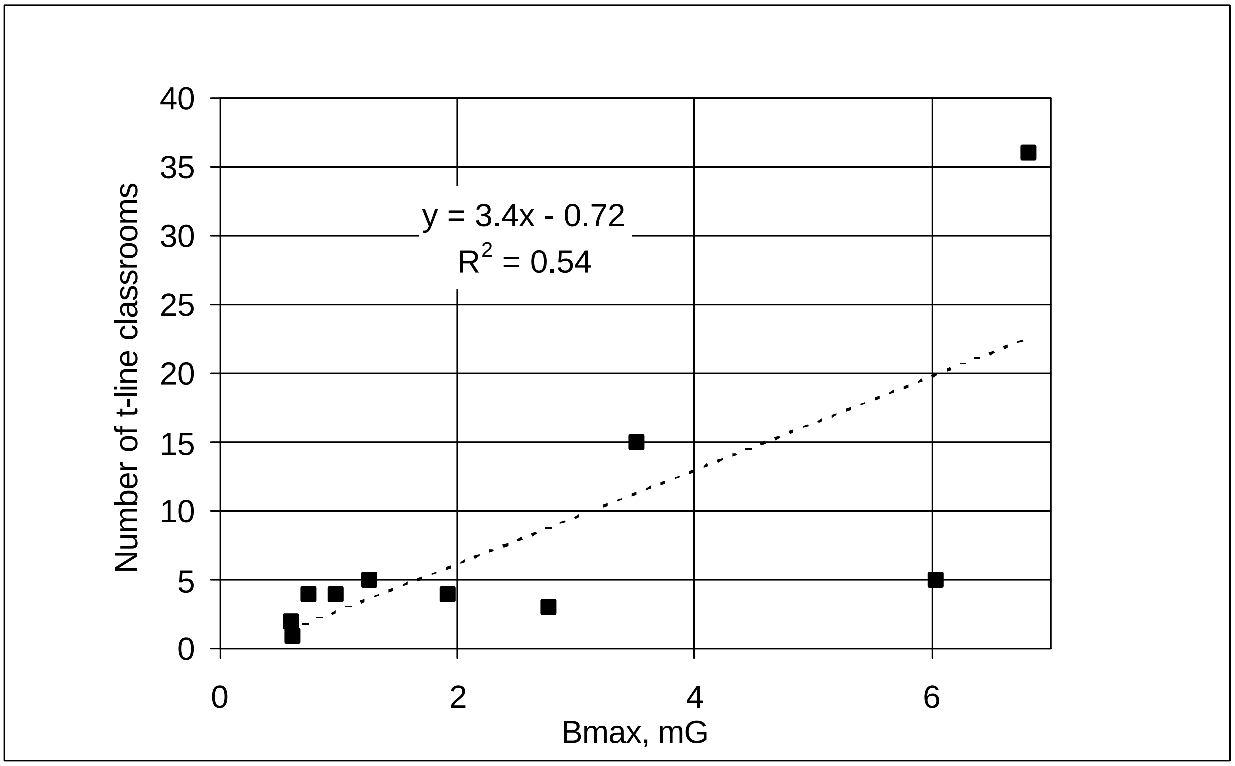

Figure 9.8. Number of transmission line classrooms per transmission line school vs. Bmax, highest transmission line classroom field in the school. Derived from Enertech 89-school database.

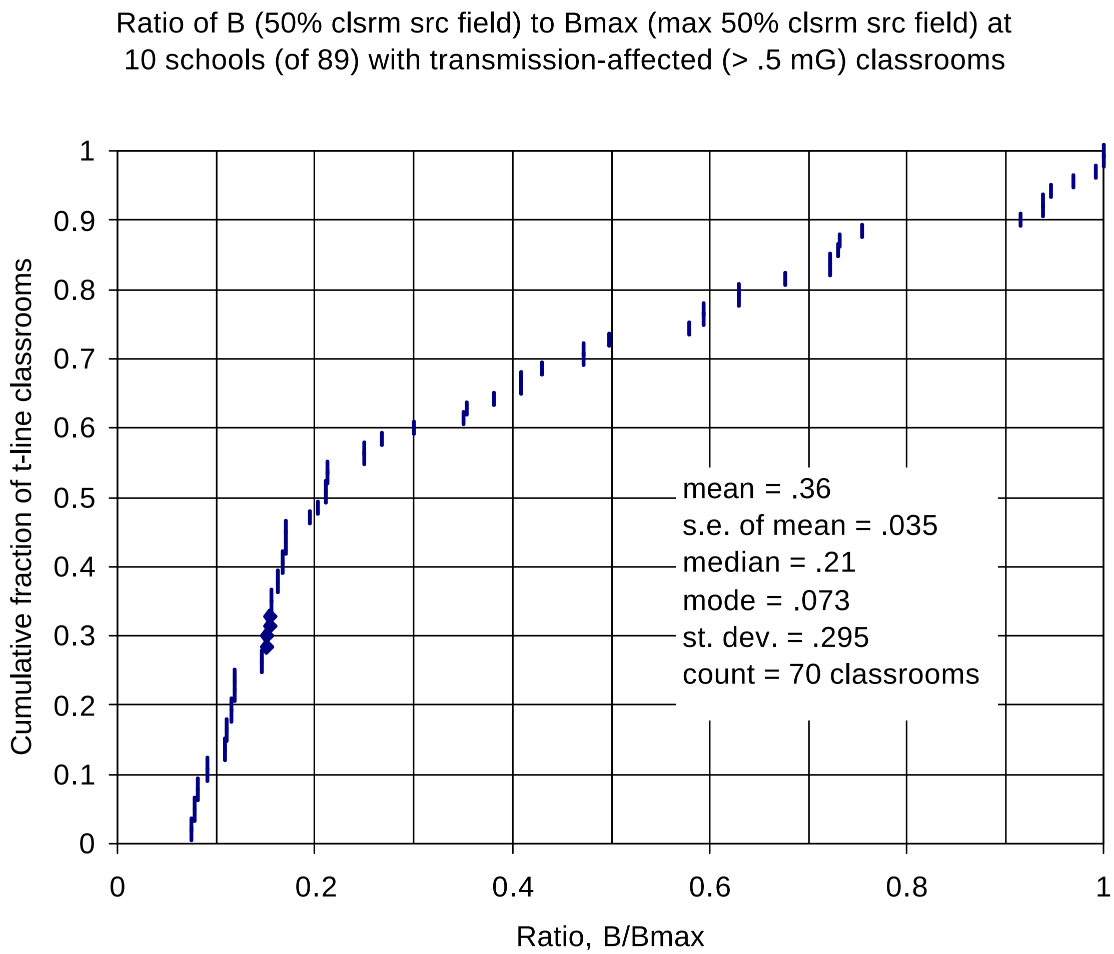

Figure 9.9. Distribution of the ratio of the 50% transmission line field in transmission line classrooms to Bmax, the maximum transmission line field in any classroom. Derived from the Enertech 89 school dataset.

Estimation of Maximum Credible Classroom Field from Transmission Lines.

(See Excel file: Tline Bmax freq distribution)

In the Enertech 89-school sample, there are 35 transmission lines at 32 schools. Using Enertech's base weights, these 32 schools represent about 1600 schools statewide, or 20% of the 7700 public schools statewide. Only 9 of the 32 schools (28%) with nearby transmission lines had at least one classroom with source fields exceeding 0.5 mG in at least 5% of the classroom area. If D is the distance from the transmission line to the nearest building and H is the line height, then the average field in that building at the point closest to the line will be Bmax (mG) = K_1 / (D+H)^K_2, where K_1 and K_2 are constants that Enertech fit to field profile data for each of the 35 transmission lines. Distances from the 35 transmission lines to the nearest school building are lognormally distributed with a median of 117 feet and a geometric standard deviation (GSD) of 2.2. Line heights are normally distributed as H=57 +/- 9.6 feet. The field profile coefficient, K_1, for this sample is lognormally distributed with median 12,300 mG and a GSD of 5.8. The field profile coefficient, K_2, is close to 2.0 for almost all lines. The correlation between K_1 and D is -0.2, suggesting that school buildings in this sample are positioned no further from large transmission lines than from smaller ones. The correlation between K_1 and H is negligible (.04), suggesting that higher current lines are no higher than lower current lines. Using these statistical parameters, we constructed a simulated data set for 1600 schools of line-to-building distance and field profile coefficient, $K_{1.}$ Since the Bmax classroom is not necessarily located on the lineward side of the school building closest to the transmission line, we adjusted the median of the distribution of D so as to produce the same fraction (28%) of Bmax classrooms over 0.5 mG in our synthetic sample as was observed in Enertech's sample. That is, if the distance to the nearest building, D_{bldg}, is lognormally distributed with median, D_{bldg}, and GSD=γ, we assume that the distance to the nearest classroom is also lognormally distributed with GSD=γ, but with a median that is larger than D_{bldg} by an amount that gives 28% of classrooms over 0.5 mG differs from that for distance to the nearest building only by a constant. The resulting synthetic distribution is shown below. According to this analysis, the maximum field likely to be encountered in this sample of 1600 is on the order of 100 mG. This is consistent with the field near the edge of right-of-way of a 345-500 kV line.

Percentiles of synthetic distribution of Bmax for 1600 schools near transmission lines.

Percentile of 1600 samples	Bmax
1	0.0023
5	0.0076
10	0.0158
25	0.0461
50	0.1667
75	0.6235
90	2.1125
99	13.7490
99.9	67.0387

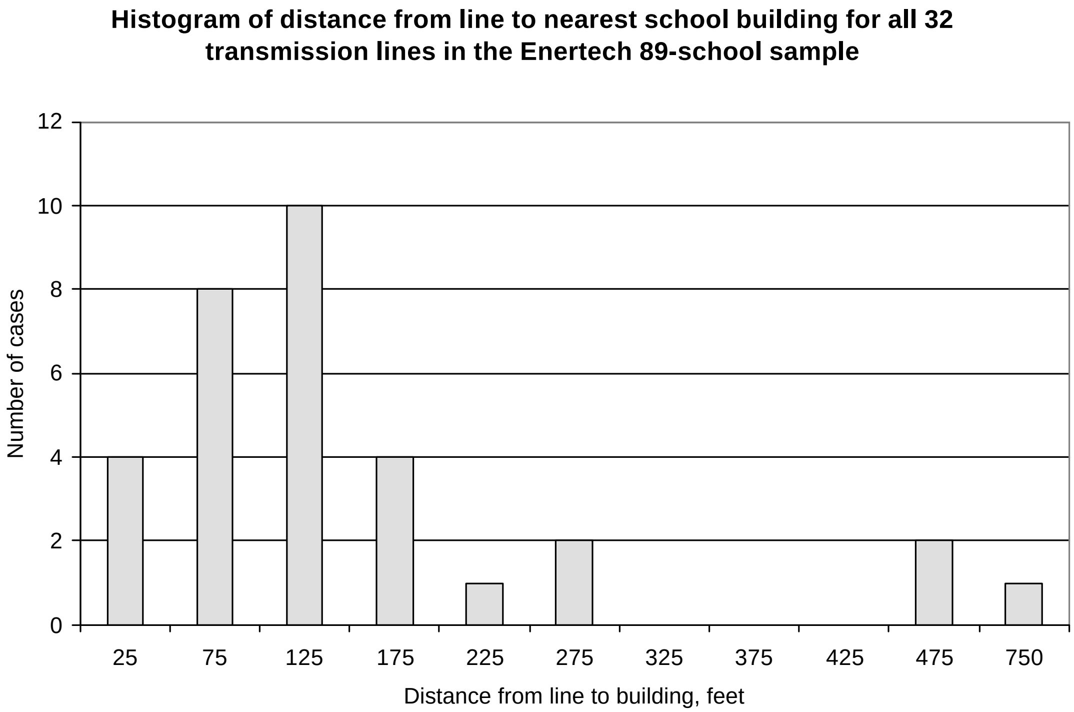

Figure 9.10. Histogram of transmission lines in Enertech 89 school sample arrayed by distance from line to nearest school building.